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KJELL ÅKERBLOM

ASTRONOMY AND
NAVIGATION IN
POLYNESIA AND MICRONESIA

STOCKHOLM 1968

**Astronomy and Navigation
in Polynesia and Micronesia
A Survey**

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Pacific Ocean

Introduction

Ever since European seafarers first penetrated as far as the island world of the Pacific Ocean, the problem of how this region was settled has been energetically debated. Where did the inhabitants come from, when did they settle the islands, and how did they set about making their way across the vast expanses of water? None of these questions has yet been given a conclusive answer; each of them has given rise to more or less sharp differences of opinion. In recent years the debate has, to say the least, become heated, above all as a result of theories advanced by Thor Heyerdahl, Andrew Sharp and others. Whatever the views one may entertain concerning these contending theories it must be admitted that the debate has provided a valuable stimulus to further scientific research which may bring us nearer to a solution of the problem.

The object of this study is to seek to provide an answer to the question how Polynesians and Micronesians were able to find their way to distant islands and island groups. In other words, it sets out to inquire into the methods of navigation used and the reliability of these methods.

To a considerable extent the debate—or, to be more exact, the dispute—has come to be concentrated on whether these ocean voyages were accidental or deliberate. In this respect the discussion can be considered rather fruitless. All that can safely be said is that most of the islands were inhabited by the time the Europeans arrived. Whether the voyages which resulted in the settlement of the islands were accidental or deliberate is a question that could only have been answered by the seafarers themselves. On the other hand, it would seem that an analysis of the method of navigation could help us to arrive at an answer to the question whether long voyages across the open seas were 'one-way' only, or whether 'two-way' voyages were possible. That is to say: Was it possible for the Polynesian and Micronesian navigators, once they had reached some unknown island, to determine their position and thereafter have a reasonable chance of finding their way back to the point of departure? Was it possible to maintain regular contacts over great distances?

The belief that the Polynesians were unusually skilful navigators and seamen who could voyage to and fro with relative ease among the various archipelagos in the Pacific Ocean has been based, above all, on the work of anthropologists such as Elsdon Best and Percy Smith.

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However, both the attitude these writers adopted and the conclusions they reached seem, in the main, to be based on an uncritical acceptance of Polynesian voyaging traditions, which on the whole they were content to regard as reliable evidence. At any rate, these scholars did not publish anything which suggests that any real attempt was made to submit this material to critical evaluation. If such an evaluation is to be carried out in a scientifically acceptable way it is necessary also to have access to data derived from archaeological and philological investigations. It is only in recent years that it has been possible to produce reasonable amounts of data of this kind from the Pacific region. The archaeological investigations, however, are still in their initial stages and it will probably be many years before they are sufficiently advanced to provide us with more than a superficial coverage of this very wide field.

Similarly, as regards the navigational methods used by these voyagers, no serious attempts were made to examine these with a view to obtaining some evidence of the reliability of the traditions and theories. This is all the more remarkable in that the ability to navigate is obviously of vital importance when one is undertaking a voyage, even a short one, across the open sea. The navigational skill of the Polynesians was simply taken for granted, as something about which there could be no disagreement whatsoever. It is only during the past ten years that this standpoint has been challenged, in the first place by Andrew Sharp in his *Ancient Voyagers in the Pacific* and *Ancient Voyagers in Polynesia*. Sharp's views, which deal not only with the problem of navigation but with that of migration as a whole, have met with strong opposition as well as some support. Briefly, Sharp maintains that the navigational methods of the Polynesians did not admit of a reliable determination of their position, and that as a result it was not possible for them to undertake deliberate 'two-way' voyages outside certain limited contact areas. In the few cases where such voyages did occur, they were the result of chance more than of navigational skill. "The view that the Polynesians settled their distant islands at the time they discovered them by unnavigated one-way voyages is both simple and realistic" (Sharp, 1963, p. 74).

Sharp's theories have been severely criticized by many anthropologists and archaeologists, though he has also received support from many writers. One of these is the American oceanist Douglas Oliver who writes: "But the proposal that these neolithic sailors, however hardy and fearless, could have followed prearranged courses over a thousand or two miles of open sea, without more precise means for locating their destinations or fixing their positions at sea, is beginning to tax the credulity of their warmest admirers" (1961, p. 69).

Thus a reassessment of the old traditionalists' view of the Polynesians as navigators is under way.

It seems clear that the question of what methods of navigation the Pacific voyagers employed is of a certain importance in the migration problem as a whole. What help does the available source material give us in arriving at an assessment of the navigational methods? Opinions are divided on this point. Sharp takes the view that "there is abundant evidence of the navigation methods used by the Pacific Islanders on the journeys they actually made" (1957, p. 41). Suggs, on the other hand, writes: "The techniques of navigation used by the Polynesians are unfortunately not known to us in any detail, and this has led some 'theorists' to hypothesize that precise methods never existed—which is a rather wilful assumption at best"; and his conclusion is that "we have very definite evidence, both from archaeological and documentary sources, of Polynesian ability in navigational matters" (1960, pp. 78, 85).

Suggs also suggests that the ability of the Polynesians to find their way across the ocean could be ascribed to "an indefinable sixth sense" (1960, p. 81). This view is shared to some extent by, among others, Parsons, who writes: "The navigational skill of the people of Oceania has won universal if not always wholehearted respect. Basically, it might seem to have been founded on that almost uncanny sense of direction which early man perhaps shared with birds and other animals, whose existence depends upon their capacity to traverse long distances to and fro . . ." (1963, p. 40).

The discussion is hardly enriched by arguments of this sort, which serve to surround the sea voyages of the Polynesians with an aura of mystery. Gatty has clearly shown that all talk of a sixth sense is quite without foundation in this context: "It seems that the prevalent misconception about the pathfinding ability of native peoples only began in the middle of the last century, and it appears to derive very largely from the loose testimony of a few explorers and missionaries" (1958, p. 49).

Obviously there is both a lack of clarity and a considerable difference of opinion concerning the Polynesian art of navigation. Regrettably, the responsibility for this state of affairs must in the main be placed on certain archaeologists and anthropologists who, in this particular case, maintain a point of view which, as often as not, is based on shaky premises and owes more to emotional thinking than to a knowledge of the facts.

Since the opinions concerning Polynesian navigation are so divided, it has been necessary for me to turn to the available sources in order to obtain as much first-hand information as possible on which to base an opinion. There is an exceedingly rich body of literature concerning Polynesia and Micronesia, but as a rule information relating to navigation

and astronomy in these areas is incomplete and very scarce. /As it has not been possible to go through more than a fraction of this literature, in the main the selection has been made with the help of the bibliographies listed in recently published books and articles dealing with navigation and migration within Oceania.

There are considerable differences between the navigational methods used in Polynesia and those used in Micronesia, and so any conclusions arrived at concerning navigation in Polynesia are not always relevant to Micronesia, and vice versa. Many people, however, have failed to appreciate this and tend to include in the term "Polynesian navigation" methods of a kind that, as far as we know, were employed only in Micronesia. The result is a sort of oceanic navigational cocktail which does not correspond to the actual circumstances. In addition, there is nothing which can be called "Micronesian navigation"; the techniques employed in the different archipelagoes vary too much for that. Consequently it will be one of the aims of this survey to seek to demonstrate the differences between these methods. ¹

If long-distance voyages out of sight of land are to be accomplished, some form of astronomical navigation is essential, and so a certain amount of astronomical knowledge is needed. In order to provide a background to an understanding of the nautical astronomy practised by the Polynesians and Micronesians, and in order to make possible an assessment of the reliability of the methods of navigation, it has therefore seemed necessary to attempt to inquire into the extent of the astronomical knowledge possessed by these voyagers.

The heavenly bodies, however, played an important role in the lives of the people even in other respects than those directly connected with sea voyages. A very rich mythology was intimately associated with these bodies; they were of no little importance where economic and ceremonial activities were concerned, and with their help it was possible to determine when the seasonal changes in the weather could be expected. Last but not least, they were used for measuring time; they were calendars as well as clocks. The scope of this essay, however, does not allow of any detailed treatment of all these different aspects. It has been possible to mention them only in passing, and the essay has instead been devoted to a survey of the astronomy of the Polynesians and Micronesians, as well as of their navigational methods.

Note. As the present survey was concluded in July 1966 it has not been possible to take into account literature published since that date.

POLYNESIA

Astronomy

1. *The Universe*

The concept of the structure of the Universe varied within the many island groups of Polynesia. However, there are so many features in common in the prevailing conceptions that it is worth while trying to sketch the broad outlines of a "Polynesian Universe", which can serve as a basis for our understanding of Polynesian astronomy. (Cf. Fig. 1.)

Over the Earth there arched a number of heavens consisting of concentric hemispheres of solid matter, resting on the plane surface of the Earth or raised up from it by a number of pillars. These heavens lay in tiers one above the other and where they met the Earth they formed circular zones. Each island group regarded itself as *te pito*, the navel of the universe, and was therefore considered to be located at the centre of this system of concentric spheres, and separated from other islands by the celestial cupolas which rested on the Earth. A journey to a distant group of islands situated within another zone of the Earth's surface was, therefore, the equivalent of a journey to another heaven. This, then, is the explanation of the frequent reference in Samoan tradition to man's communication with heaven. When the Europeans reached Polynesia for the first time, the Samoans thought that the newcomers had broken through one of the solid cupolas of heaven, and for that reason they called them *papalangi*, heaven-bursters. (Williamson, 1933, p. 90.)

Conceptions regarding the number of heavens varied between about three and twelve. In Tonga and the Tuamotu Islands it was assumed there were nine, in the Society Islands seven or ten. According to Malo the Hawaiians imagined the space above the earth to be divided into nine strata and thought the heavenly bodies had their orbits in the most distant of these (1951, p. 12). In the highest of the nine Tuamotuan heavens were the stars, lower down was the sun and nearest to the earth was the moon. The heavenly bodies rose through openings in the eastern horizon and set through similar openings in the western horizon. The stars constantly followed the same path, in contrast to the sun, which therefore caused the days to vary in length (Henry, 1938, p. 348). It was believed that when the heavenly bodies sank below the horizon they travelled underneath the Earth back to the points on the horizon where they had risen. In the Society Islands it was supposed that the sun was

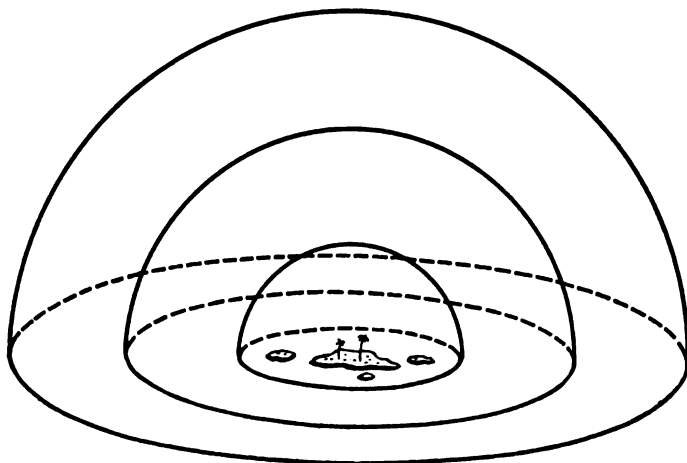


Fig. 1. The Polynesian sky domes (after Makemson, 1941).

made of a substance resembling fire, and that every evening it sank hissing into the sea, after which it travelled from west to east during the night by a submarine passage (Williamson, 1933, p. 114).

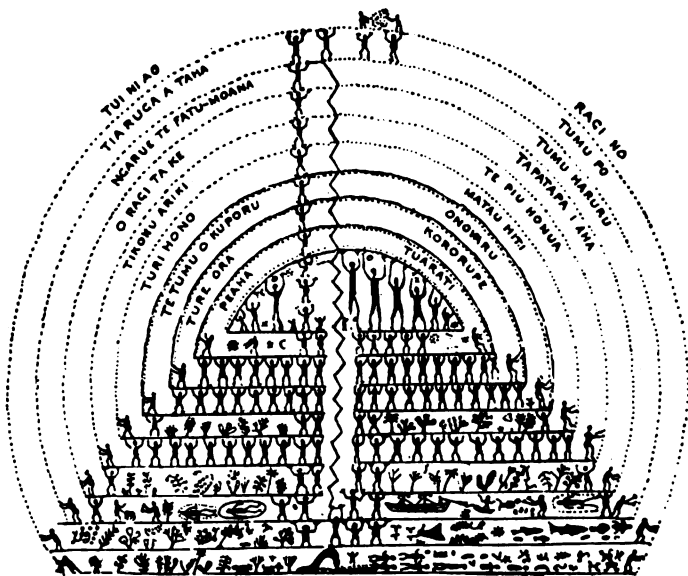


Fig. 2. *The nine heavens of the Tuamotuans (after Henry, 1928).*

2. *Some astronomical concepts*

In Hawaii the HORIZON was called *kukulu-o-ka-lani* "the walls of heaven; the border of the sky where it meets the ocean horizon". *Kukulu* reflects the influence of cosmology on the astronomical terms. *Kukulu* means "wall" or "vertical structure", and is used to denote the four pillars which were the principal supports of the heavenly dome (Makemson, 1938, p. 372; Malo, 1951, p. 10), as well as the wall which encircled the earth and prevented the water in the ocean from running out (Makemson, 1939, p. 19). On Pukapuka the horizon was called *te tawa o te langi* "the side of the sky" (Beaglehole, 1938, p. 326).

In Hawaii the ZENITH was called *ka hookui*, "the point of juncture", i.e. where the sweeping curves of heaven's arches meet (Malo, 1951, pp. 9, 11). The Maori called the zenith *Puanga*, which was also the name of the star Rigel in Orion's Belt. Nowadays the declination of Rigel is 8°S. New Zealand extends between latitudes 37°S and 46°S, for which reason a zenith star must have a corresponding declination. Makemson is therefore of the opinion that this name for the zenith is an indication that the immigrants must have originated from an area in which Rigel was the zenith star, that is to say, equivalent to about latitude 8° south (1941, p. 30).

The CELESTIAL EQUATOR is the earth's equator projected on the celestial sphere. In Hawaii it was called *ke Ala i ka piko o Wakea*, "the road to the navel of *Wakea* (the Sky Parent)", i.e. to the centre of the world (Fornander, 1878, p. 127). According to Best, *piko o Wakea* instead applies to the ecliptic (1922a, p. 12). Among the Maori the corresponding name *te pito a Rangi* "the navel of *Rangi* (the Sky Parent)" is interpreted by Smith as the ecliptic (1913, pp. 167—168). Fornander supplies yet another name for the celestial equator, *ke Ala-ula a ke kuukuu*, "the bright road of the spider" (1878, p. 127). However, Makemson holds the view that this expression refers to the ecliptic (see below), since "the path of the spider refers to the spiralling motion of the sun northward and southward during the year" (1938, p. 375).

3. *The sun and its motion*

To an observer on the Earth the sun appears to move across the sky. Since the fixed stars cannot be seen at the same time as the sun, this motion cannot be observed directly, but it is possible to establish it by observing the stars which can be seen on the eastern part of the horizon just before sunrise. If their position has been noted on a certain day it will be found that after a few days they are appreciably higher in the

sky at the same time in the morning. As the fixed stars change their positions only very slightly, this means that the sun has moved in relation to them.

At different times of the year the greatest altitude reached by the sun will vary. Consequently the sun also has a north-south movement. If the position of the sun in the sky is determined at the same time day by day during the year and if these points are connected we then obtain the path along which the sun appears to move, i.e. the ecliptic. This intersects the celestial equator at the vernal and the autumnal equinoxes. At these times the sun is directly overhead at noon on the equator (the declination is nil), day and night are of the same length in all parts of the world, and the sun rises in the east and sets in the west. In the temperate zones the sun's changes of altitude, and the corresponding changes in the length of the days are easy to notice, not least in connection with the conspicuous changes in temperature. A division of the year into four seasons seems quite natural. Within the tropical regions of Polynesia, where the sun is much nearer the zenith, the corresponding variations in the length of the days and in day and night temperatures are considerably smaller, and a division of the year into two seasons, one dry and one rainy, is usually sufficient. In spite of the fact that the change in the sun's altitude is not so conspicuous, the Polynesians were quite well aware of the sun's annual motion and were able to fix the times for the summer and winter solstices (the most northerly and most southerly positions reached by the sun) with the aid of simple observatories.

According to HAWAIIAN tradition these observations were carried out by an astronomer-priest from a temple on the east coast of the island. There an observation platform was sited in relation to two high cliffs in such a way that a sight line from the platform to the more northerly of the cliffs marked the summer solstice, while a sight line to the more southerly one marked the winter solstice. The path of the sun at the time of the summer solstice, when the sun is in its most northerly position (declination), corresponding to the Tropic of Cancer on the surface of the Earth, was called *ke Ala-nui polohiwa a Kane*, "the black shining road of Kane". The orbit at the time of the winter solstice, when the sun reaches its most southerly position (declination), corresponding to the Tropic of Capricorn on the surface of the earth, was called *ke Ala-nui polohiwa a Kanaloa*, "the black shining road of Kanaloa". (Fornander, 1878, p. 127; Makemson, 1938, pp. 375, 378.)

On PUKAPUKA, lat. 11°S, the ecliptic was called *te Ala-o-te-la*, "the path of the sun". That part of the ecliptic where the sun's declination is northerly (the sun is north of the equator) was called *te Lua-poto*,

“the short hole”, and that part where the declination is southerly was called *te Lua-loa*, “the long hole”. *Poto* refers to the short days of the winter half-year, while *loa* refers to the longer days of the summer half-year. (The difference at this low latitude, however, is comparatively small.) The name *lua*, “hole”, reflects the belief that the sun rose and set through a hole in the horizon. (Beaglehole, 1938, p. 349.) Makemson gives *Lua-poto* and *Lua-loa* the sense of winter solstice and summer solstice respectively (1941, p. 85). The corresponding expressions on TAHITI were *Rua-poto* and *Rua-maoro* or *Rua-roa* (Fornander, 1827, p. 127; Henry, 1928, p. 81).

Detailed descriptions of how observations of the sun were carried out on MANGAREVA have been supplied by the French missionary Honoré Laval (1938, pp. 213—214) and by Peter Buck (1938, pp. 414—415). Four observation sites have been noted in this island group. The observations of the solstices were carried out either at sunrise or sunset, depending on the location of the site in relation to the free horizon. Where no natural aiming points existed for the determination of the sun’s northernmost and southernmost positions, two stones were set up to form sights which indicated these directions exactly.

As a result of the archaeological investigations carried out on EASTER ISLAND under the direction of Heyerdahl it has been found that several *ahu* were probably orientated with reference to the position of the sun at the time of the summer solstice (December in southern latitudes) or at the equinox. Evidence to support this theory is supplied by the discovery of what is considered to have been a solar observatory at one of the places where religious rites were performed. At this observatory the astronomer could, by means of a shadow pin, determine the times for the two solstices and the equinoxes. (1961, pp. 94, 189, 228.)

The Maori in NEW ZEALAND used the same name, *marua-roa* to denote the winter and summer solstices, and also to signify the time of the year or the period during the winter and the summer when the sun was near its turning point. When it was felt necessary to specify which solstice was being referred to, the word *oronganui*, “summer”, was added to *marua-roa* to indicate the summer solstice; it would appear that the term *marua-roa* used by itself referred to the winter solstice. (Best, 1922*a*, pp. 13—14 and 1922*b*, p. 39; Makemson, 1941, pp. 85—86). That the Maori were familiar with the annual motion of the sun is evident from the legend of *Hine-raumati*, “the Summer Maid”, and *Hine-takurua*, “the Winter Maid”, which personified summer and winter: “The sun spends part of the year with the Winter Maid in the south,

afar out on the ocean. In the month of June occurs the 'changing of the Sun', and he slowly returns to his other wife, to the Summer Maid—she who dwells on land . . . And so acts the Sun in all years" (Best, 1922*a*, p. 14 and 1922*b*, p. 40). No information is available regarding the way in which solar observations were carried out in New Zealand, though a statement supplied by a Maori might be taken as meaning that certain aids were in fact used during astronomical observations. As a boy this Maori had seen his father "put sticks in the ground and observe the stars. If the observed star moved south, the season would be bad, if it moved north the season would be dry and good" (Beattie, 1918, p. 145).

4. *The classification of the stars*

In the traditions from HAWAII five different classification systems for the heavenly bodies have been preserved. Each system contains between two and five main groups. (Cf. Makemson, 1939*a*, pp. 589—596).

The great importance heavenly bodies had in connection with navigation is clear from the fact that four of these systems included a group consisting of "navigational stars" or "canoe steerer's stars". Another group comprised "people's stars" or "stars ruling the months". The rising and setting of these stars constituted the sign for the beginning or ending of various kinds of activity within the community.

According to a classification system described by Kepelino (Beckwith, 1932, pp. 78—82) the stars were divided in two classes "fixed stars" and "moving stars".

"Fixed stars" were divided into three groups:

(a) "Guiding stars". When they rose these stars guided the navigator to his destination, "like the *Hoku-Lea* (Arcturus?) that rises over the Hawaiian Islands and the Southern Cross over the Tahitian and so forth". *Kiopaa* (Polaris) was also included in this group.

(b) "The stars of heaven" (*Lalani*, "the Milky Way") or "ruling stars".

(c) "Greater stars". The sun, the moon and Venus (*Hoku-loa*) were included in this group. The sun indicated the east and the west, the moon formed the basis of the calendar and its phases supplied the names of the different days of the month. Venus served as a guiding star for sailors and as a clock for farmers.

"Moving stars". These stars were of no importance and their only function was to give the Earth a little light during the night.

It seems probable that in southern NEW ZEALAND there can be traced certain reminiscences of a classification of the heavenly bodies

which brings to mind that found in Hawaii. In Beattie's *Traditions and legends* we find: "The stars *Autahi* (Canopus) and its pointer *Takurua* (Sirius) and *Puaka*, and those under *Matariki* (the Pleiades) are in east, while the *Wero* stars are in the west. The latter stars gave the sailing direction, while the former denoted weather and seasons. *Wero-i-te-ninihi* and *Wero-i-te-kokota* (Aldebaran) are fixed stars, but *Wero-i-te-aumaria* (*ao-marie*) only appears between the two former occasionally" (1918, p. 154). *Puaka* probably corresponds to the form *Puanga*, i.e. Rigel, prevalent in the rest of New Zealand. *Puaka* is also the name given to an unidentified star in the Marquesas Islands.

The stars seem to be divided into the same classes as in Hawaii, "fixed stars" and "moving stars". In the former class *Wero*-stars probably correspond to the "guiding stars" group and *Autahi*, *Takurua* and others, the "stars of heaven" group, i.e. the stars which governed certain economic and ceremonial activities.

However, Beattie's reports are altogether too fragmentary and vague to permit a more detailed interpretation. It seems very likely that his informant merely repeated to him an incomplete version of the traditions, being quite ignorant of their true meaning. For example, the informant says that the navigational stars, the *Wero*-stars, are in the west. Does this mean that the sailors navigated only by the stars that were setting? It seems most improbable that this could be the case.

5. Zone division of the celestial sphere

On the basis of the traditions the American astronomer Makemson has reconstructed the HAWAIIAN division of the celestial sphere into zones (1938, pp. 378—381, and 1941, p. 21).

In Fig. 3 is shown the celestial meridian (NZS), which was formed by a line drawn from *Hoku-pa* (Polaris) through the zenith to *Newe* (the Southern Cross). The eastern half of the sphere was called *ke alaua a Kane*, "the dawning bright road of Kane", the western half *ke alanui maawe ula a Kanaloa* "the much-travelled highway of Kanaloa". The zones were four in number and they were defined by the parallels of declination which denote the path of the sun at the time of the two solstices, the celestial equator and a southerly parallel of declination whose angular distance from the equator is twice that of the other two parallels. In the main the zone division covers the southern hemisphere, since within it were the stars which acted as guides to the island groups known to lie to the south.

Makemson based her reconstruction on material published by two Hawaiians, Malo and Kamakau. However, this material by no means

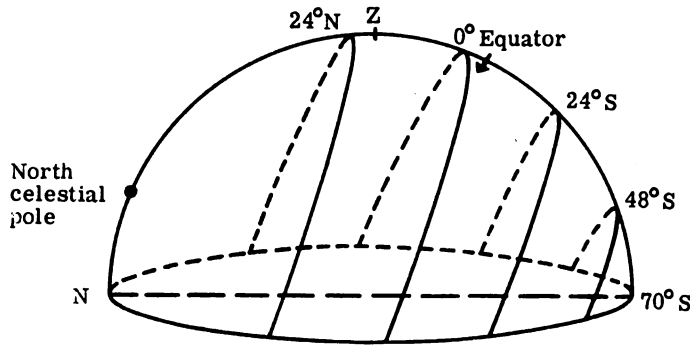


Fig. 3. Hawaiian division of the celestial sphere into zones (after Makemson, 1938).

justifies such an unambiguous interpretation as that presented by Makemson. The zone division can equally well be assigned to the horizontal plane instead, and be associated with the Polynesian beliefs concerning the structure of the universe, already referred to. (Fig. 1; cf. Fornander, 1878, pp. 15, 23; Beckwith, 1932, p. 54; Malo, 1951, pp. 8, 10.) One is forced to regard the reconstruction as very doubtful since the evidence on this point is difficult to interpret as well as contradictory. The reliability of the sources is also open to question, especially as far as Kamakau is concerned, and it was he who provided Makemson with her most important arguments. With reference to the often-quoted evidence derived from Kamakau, which has proved to be strongly influenced by western geographical knowledge, Emory says: "As representing reliable ancient Hawaiian traditions, and therefore as having significance for historical reconstruction, it is valueless" (1959, p. 32). In view of this the possibility cannot be entirely ruled out that Kamakau's astronomical information will also have to be judged in the same way. Makemson's reconstruction is in close agreement with the description Grimble has supplied of the celestial sphere of the Gilbert Islands in Micronesia (1931, pp. 197—214). Grimble's detailed account is based entirely on his own primary material and it seems as if Makemson has been unduly influenced by it in her attempts to reconstruct the Hawaiian celestial sphere.

Even though Makemson's reconstruction ought to be taken with considerable reservations it seems certain that information concerning a zonal division of the celestial sphere is to be found in the traditions from Hawaii. On the other hand, it is not known what form this division took.

In the TONGA ISLANDS the celestial sphere was divided into three zones. *Fakatonga*, "southward", i.e. the southern zone; *Faka-loto-langi*, "mid-sky", i.e. the mid-sky zone; *Faka-tokelau*, "northward", i.e. the northern zone (Collocott, 1922, p. 4).

A corresponding division was assumed on other islands, including NUKUMANU, one of the Polynesian outliers. The stars moved in *Takina ha tokelau*, i.e. nördliche Strasse; *Takina ha Manu*, i.e. Strasse des *Manu*; *Takina ha kupu*, i.e. Strasse des Südens. *Manu*, which denoted the middle zone, was a splendid constellation stretching across a considerable part of the southern sky. In this were included, *inter alia*, Sirius (declination 17°S) and Orion's Belt (Rigel's declination 8°S), which passed close to the zenith of Nukumanu (latitude 5°S). (Sarfert & Damm, 1929, pp. 191, 195.)

6. Summary

"The use to which the Maori put his knowledge of the heavenly bodies and their movements was in several instances a scientific one, as, for instance, when he navigated his vessels by them during deep-ocean voyages, when he watched for the helical rising of stars to mark the commencement of the Maori year and of certain seasons and activities" (Best, 1922a, p. 4).

This characterization of Maori astronomy can be extended to apply also to the rest of Polynesia. The difficulties one encounters when trying to give a comprehensible picture of Polynesian astronomy, regarded as a science, are, however, considerable. Fieldworkers only roused themselves to collect data from this sphere when it was too late and a large part of the knowledge had been forgotten, leaving only a few fragments behind. "With the decadence of sea voyaging much of the old-time lore fell into disuse and was lost" (Beaglehole, 1958, p. 347). Ethnographers were also often unwilling to tackle astronomy. The whole thing was too much trouble; they knew little about such matters and consequently, it was difficult for them to identify the heavenly bodies. This task was not made any easier by the fact that the Polynesian constellations only rarely agreed with ours. The German ethnographer, Krämer, engaged on field work in Samoa, was conspicuously successful in declining to accept information that a willing informant sought to force on him:

"Mein alter Freund Le'iato von Tutuila gab sich grosse Mühe, mir diese Art der Navigation zu erklären, und als er einmal hierzu eines Abends gekommen war und seinen Vortrag wegen einiger manglender Sterne nicht vollenden konnte, wechte er mich wenigen Stunden später während der Nacht schon wieder, und obwohl ich eine Festlichkeit zu Apia in der Zwischenzeit erledigt hatte, liess er mich nicht los, bis die Sonne aufging. Ich muss gestehen, dass ich nicht alles kapiert habe, wofür ich nicht einmal die Festlichkeit verantwortlich zu machen brauche, denn ich bin ein zu schlechter Astronom und überdies schien mir auch die Sache nicht so ganz einfach zu liegen". (1903, p. 244.)

From the little that Krämer has published about this lesson, barely one page, all that we can deduce is that we have been denied some particularly interesting information.

A small quantity of astronomical data can be gleaned from the myths and traditions, which might serve to complement the factual information at our disposal. It must be admitted, however, that our knowledge of Polynesian astronomy is severely limited and that we no longer have any prospect of adding to it.

Briefly, what we know about Polynesian astronomy is as follows:

(a) The Polynesians knew of and had names for a great number of stars (in the case of the Maori probably close on two hundred).

They were well acquainted with the apparent motions of the stars and knew that they rose and set at the same points on the horizon and that the times at which they rose and set changed continuously during the year.

It was known that the appearance of the firmament changed when the observer changed his latitude.

In Hawaii Polaris indicated the north and the Southern Cross the south. Within the rest of Polynesia, where Polaris is not visible, it is probable that the south was determined by means of the Southern Cross.

It is possible that true north-south could be obtained by observing the stars when they were on the meridian. There is no confirmation of this, however.

The planets could be distinguished from the fixed stars, though navigators in all parts of Polynesia had not realized that Venus is both the morning and the evening star.

The stars were divided into groups with respect to application, and so one group consisted of navigational stars.

The celestial sphere was divided into zones. It is possible that the zonal division was used for instructional purposes and in order to give the position of a star in the celestial sphere.

(b) The apparent motion of the sun throughout the year was observed and, with the help of simple observatories, the Polynesians could determine the times of the two solstices. With the exception of Easter Island, there is nothing to suggest that they observed the equinoxes in a similar way.

(c) Other astronomical concepts previously mentioned were the zenith and the celestial equator. However, the interpretation of the Polynesian names which are said to designate these concepts is so uncertain that one cannot definitely state that they formed part of Polynesian astronomy. From the nautical-astronomical point of view they seem to be of no

importance to the Polynesian navigator. It is only his western colleagues, who employ instruments for measuring altitude, chronometers and tables, that depend on a celestial equator and a precisely defined zenith.

It is also probable that the concept which is translated as "zenith" in the ethnographical literature is intended only to refer in general terms to an upwards direction, above the head or the like. A certain confirmation of this view can be found in the star calendar of Pukapuka. "*Mataliki* (the Pleiades) directly overhead in the sky is a sign of turtles coming to lay eggs on the outer beaches" (Beaglehole, 1938, p. 351). Pukapuka lies at latitude 11°S , the declination of the Pleiades is about 24°N . Consequently the constellation will not be nearer than 35° to Pukapuka's zenith, and this is some way from being "directly overhead", if this expression is to be taken literally.

Polynesian astronomy, as it has been outlined here, was, despite its apparent simplicity, adequate as a basis on which to evolve a navigational method, without which ocean voyages would have been impossible.

Navigation

During sea voyages the Polynesian navigators did not rely entirely on the heavenly bodies for the steering of an intended course. They had just as much recourse to the wind and the direction of the ocean swell, which are fairly constant over vast areas of the ocean during the trade-wind season. Cloud formation over islands, reflections from the lagoons of atolls, changes in the direction of the swell and other signs that land was near were closely observed so as to ensure landfalls. In the following section the various methods employed will be dealt with separately, and in the process the basis provided by the sources will be described and then analysed.

ASTRONOMICAL NAVIGATION

1. Basis

The available evidence concerning Polynesian astronomical navigation from the time of the first contacts with the Europeans is consistent as far as factual content is concerned, but it is very scanty indeed. No precise details are given and it is probable that none were known to the Europeans.

Sir Joseph Banks, who accompanied Cook on the latter's first voyage, writes:

"In their long voyages they steer in the day by the sun and in the night by the stars: of them they know a very large number by name, and the cleverest among these will tell in what part of the heavens sky they are to be seen in any month, when they are above the horizon" (1896, p. 162).

Andia y Varela (1774) first gives an account of how the course is set with the help of wind and sea and thereafter supplies certain details concerning navigation by stars:

"When the night is a clear one they steer by the stars; and this is the easiest navigation for them, because, these being many (in number), not only do they note by them the bearings on which the several islands with which they are in touch lie, but also the harbours in them, so that they make straight for the entrance by following the rhumb of the particular star that rises or sets over it; and they hit it off with as much

precision as the most expert navigator of civilized nations could achieve" (Corney, 1915, p. 286).

No further information relating to the way in which the heavenly bodies were used for navigation was available until this century. Ethnographers, missionaries and explorers in the 19th century usually contented themselves with stating briefly, and in passing, that the Polynesians "set course and steered by the stars". Ethnographers of more recent times have occasionally shown a greater interest in the problem and have tried to obtain more detailed information. But they were too late; by then the old art of navigation had almost been forgotten altogether. The results have therefore been somewhat meagre. Essentially, they are limited to what is summarized here.

TIKOPIA. When voyaging to Anuta, 70 miles NE of Tikopia, the sailors waited for a favourable wind and then set sail at dusk so as to be able to take advantage of the stars when setting course.

"...the major navigational guide is the Star-path, the 'Carrier' (*Kavenga*). This is a succession of stars towards which the bow of the canoe is pointed. Each is used as a guide when it is low in the heaven; as it rises up overhead it is discarded and the course is reset by the next one in the series. One after another these stars rise till dawn, and at some times of the year a few still remain to rise when dawn breaks. It is to have the advantage of the Star-path, above all, that the voyage to Anuta is made at night. Each star is named, and according to the Arika Kafika, the Star-path to Anuta has nine stars in all". (Firth, 1954, p. 91.)

Beatrice Blackwood gives a description from Melanesia of navigation by means of stars during a voyage between Buka (northern Bougainville) and Nissan, 40 miles NNW of Buka, and this description agrees in every respect with that above. Ten stars, not identified, served as guides for the helmsman. In certain respects, however, her information is not quite correct. The same stars are described as being leading stars ahead on the outward voyage as well as on the homeward voyage, both of which began at dusk. This is impossible. On one leg of the voyage the stars concerned must obviously have been taken astern. (1935, pp. 381—382.)

PUKAPUKA (Danger Islands). Beaglehole has supplied a description of course-setting by stars for voyages from Pukapuka to Niue, Upolu and Olosenga (the Samoan Islands), and the Gilbert Islands (1938, pp. 351—353).

(a) Pukapuka to Niue, about 600 miles SSW.

"The course from Pukapuka to Niue was equal to the bearing of α and β Centauri when low in the sky to west of south. Informants emphasized that the stars must be low in the sky; evidently the old navigators were aware of the Centauri's rapid change of bearing when at a higher altitude."

According to certain informants the voyage was made by way of Nassan, an island situated about 40 miles SE of Pukapuka.

Beaglehole points out that during the months July to September when α Centauri sets before midnight, the wind blows steadily from a direction between E and NE. It is thus a favourable wind for such a voyage.

(b) Pukapuka to Upolu, about 360 miles SW.

"Informants state that the old navigators steered a course to Upolu which was equal to the bearing of Antares (*Melemele*) when low in the sky to the westward."

For the return voyage from the Samoan Islands to Pukapuka the following sailing directions were given:

"... the Pukapukan navigators sailed from Upolu to Olosenga (about 60 nautical miles E of Tutuila); then sailed on to Pukapuka using ζ , ϵ , and δ Orionis (*Te-Tolunga-Maui*) as their star course."

Here, too, Beaglehole points out that the stars referred to as steering stars were in suitable positions at the time of year during which the winds were favourable for these voyages.

(c) Pukapuka to the Gilbert and Ellice Islands, minimum distance about 830 miles WNW.

"In sailing to the Gilbert-Ellice Islands, informants state that the navigators used Altair (*Tolu*)... It is visible at setting during the latter half of the trade-wind season when the weather is favourable for the voyage."

The value of the sailing directions supplied from Pukapuka must, however, be considered dubious. It is possible that they are a result of post-European contact. Dening, who has dealt with the geographical knowledge of the Polynesians, is of opinion that this is the case, because of the "very uniqueness" of detail in the directions (1963, p. 119). In his commentaries Sharp calls attention to the fact that the sailing directions supplied give no explanation of how the navigator compensated for the canoe's lateral displacement due to currents (1963, p. 89). The fact is that if one plots the course steered on a chart one comes so near to one's destination that the necessary allowance for current simply cannot have been made.

There are also other aspects of this matter which throw doubts on

the authenticity of the information. The voyages mentioned here are of such a length that even the shortest of them would require about three to four days. During this time the navigators were guided by only one star. This could only be used when it was low on the horizon, in other words for about one hour. How were they able to steer their course during the remaining 23 hours? The scantiness of the information is obvious if one compares it with the account from Tikopia, according to which no fewer than nine stars were used to sail a distance of only 70 miles. Regardless of the fact that one is thus obliged to regard the information from Pukapuka as unreliable, there is, on the other hand, nothing in the description which conflicts with the principles of Polynesian astronomical navigation which have been dealt with previously: course-setting by means of horizon stars.

THE SAMOAN ISLANDS. In his monograph on Samoa (1903, pp. 245—246) Krämer gives an account of a voyage from Tutuila to Manua (about 60 miles) undertaken by two Samoan sailors. This account contains certain interesting details regarding astronomical navigation. On sailing they set course by taking a high mountain on Tutuila as their transit mark astern. When dusk came the Evening Star rose on the bow. Then the stars *Faipa* and *Tulalupe* (unidentified) showed above the eastern horizon. By degrees the guide stars came into view and the navigator successively reset his course, steering first by *Toloo*, and thereafter by *Sumu* (the Southern Cross), *Luatagata* (α and β Centauri; according to Makemson Castor and Pollux), *Ta'elo*, *Ti'otala Amoga* (the Belt of Orion). At dawn the canoe crossed the reef at Manua.

The course from Tutuila to Manua is about 088° . At this latitude the Belt of Orion rises approximately due east and so the constellation could quite well have been used as a guide during part of the voyage. This is in close agreement with the details given on Pukapuka in connection with the same voyage. On the other hand the Southern Cross, like α and β Centauri, rises far down on the southern horizon, at a bearing of about 150° to 160° , which means that neither of these two constellations could possibly have been used as steering stars. It is also stated that the Southern Cross and Centaurus appear before the Belt of Orion. In point of fact it is the other way round. Either Krämer has inaccurately reported what he was told, or he has wrongly identified the stars, or else the original facts have become distorted with the passage of time. However, the reference to the Southern Cross as a steering star can also be taken as an indication that the Samoan navigators determined north-south with the help of this constellation.

In the same work Krämer has supplied further information of interest (p. 247). It is probably a summary of details that the informant forced upon the reluctant ethnographer on the occasion referred to earlier. On the whole navigation seems to have been carried out in accordance with the following principles:

(a) Two stars low on the horizon with a difference in azimuth of 180° were used to indicate the course to the destination, i.e. a rising and a setting star. The canoe was aligned between these stars, taking one dead ahead and the other dead astern. If the alignment of the two stars and the canoe was not as described, the canoe was off course, either to the north or to the south of the course line, and the course was corrected accordingly.

Krämer assigns this method mainly to east-west courses. As an example he cites the voyage between Tutuila and Manua, when Orion's Belt was used as steering star ahead. As has been mentioned above, the azimuth of Orion, when rising, corresponded closely with the course to Manua. If the canoe met with bad weather during the voyage

"... so suchten sie nach einem untergehenden Stern, der in selber Breite und um dieselbe Zeit untergeht, wenn der Orion aufgeht, wie z.B. der Arcturus und Bootes. Peilte nun einer nach hinten nach dem untergehenden Stern und einer vorne nach dem aufgehenden und stand das Schiff nicht in der Linie, so konnten sie leicht erraten, ob sie zu weit nördlich oder zu weit südlich aus der Linie geraten waren. Diese Peilung nach vorne und achtern zugleich war eine der Kunstfertigkeiten der alten Schiffer" (1903, p. 247).

Here, however, there are three incorrect statements. Orion and Arcturus (α Bootis) are visible simultaneously when the former is setting and the latter rising, not vice versa. On this occasion the difference in bearing between these two stars is not 180° but about 160° , and in addition their altitudes are not particularly favourable. Therefore, Orion's Belt and Arcturus cannot have been used together in the way Krämer has described to indicate the course between Tutuila and Manua. The description is nearer the mark if Arcturus is replaced by Altair. The difference in bearing between Altair and Orion's Belt is about 170° . (The third incorrect statement is dealt with in the section on the analysis of method.)

(b) On northerly and southerly courses the Southern Cross and the Great Bear were used as steering stars when on the meridian (when they reached their maximum altitude). The Southern Cross is then in an upright position, which makes it easy to decide when the transit occurs and the constellation indicates true south.

(c) If it was not possible to adopt either of the two methods mentioned above, the navigator instead used three stars lying close together in a line which passed through the observer's zenith. Krämer cites Orion's Belt as an example. (However, this constellation is never exactly in zenith anywhere in the Samoan Islands, but culminates some 10° lower.) Krämer describes the method as follows:

"Es legte sich dann einer der Schiffer auf den Rücken in den engen Schiffsraum des Bootes, natürlich längsschiffs, und sah er nun die drei Sterne gerade über sich oder vielmehr einen in der Mitte, den andern rechts und den dritten links, so konnte er danach dem Steuermann seine Direktiven geben" (1903, p. 247).

Krämer was unable to identify with certainty the names of the various "Dreigestirne" used by the Samoan navigators, but he formed the impression that they belonged to certain star groups in Delphinus and Scorpius. Delphinus lies about 25° — 30° north of Samoa's zenith (mean latitude 14° S), and the southern part of Scorpius is as far south again. It is therefore hardly probable that these constellations were used for navigation according to this method at the latitude of Samoa. However, it could be that they served as navigational stars for Samoans who embarked on long voyages involving a considerable change in latitude. It should be noted that Delphinus, for instance, is in an observer's zenith at about latitude 15° N, equivalent to about one degree of latitude somewhat north of the Marshall Islands.

An indication that the Belt of Orion, when culminating, has served as a steering star on Tokelau is apparent from the following:

"*Tolu*: the three stars in the Belt of Orion. In their zenith these are a direct guide from Nokunono to Atafu" (Macgregor, 1937, p. 90).

What is not made clear, however, is whether the observations were carried out in the same way as on Samoa and if this is thus a question of a similar method of navigation, "Dreigestirne".

It is difficult to know how much credence should be given to information given by Krämer on navigational methods within the Samoan Islands. It is very brief, and besides being incomplete is marred by certain factual errors; moreover, Krämer himself admits that he is anything but familiar with astronomical matters. In principle, though, there is nothing that is in direct conflict with what we have learned about Polynesian navigation from other sources. However, it is only in Krämer's writings that we come across a navigational system involving the "Dreigestirne" method, and it is therefore regrettable that his description is so sketchy as to defy any attempt at interpretation.

THE TONGA ISLANDS. As was the case in the Samoan Islands, "guide stars were observed astern as well as ahead and the boat was kept in line with them" (Collocott, 1922, p. 4).

OTHER. Statements of the type "*Na tangata* — these two stars are guides for voyages from Tokelau to Samoa" (Macgregor, 1937, p. 89) appear sporadically in the literature. As they do not add to our knowledge of the methods of navigation, no attempt has been made to present a synopsis of such items.

What has been outlined above comprises, to the best of my knowledge, all the known material that can be of value for an analysis of the navigational methods of the Polynesians. In certain voyaging traditions and legends there also exist more or less vague directions for voyages between Tahiti and New Zealand and between Tahiti and Hawaii. However, these "sailing directions" are of such a special nature that they do not seem to be relevant to an analysis of navigational methodology, and so they will be dealt with separately.

The following analysis of method is based entirely on the material presented here. In this connection, however, it seems appropriate also to examine the hypotheses that have been put forward from various quarters concerning Polynesian navigational methods. The reason for this is that these hypotheses have been accepted by non-specialists as representing methods actually used, and as such have served as arguments in the discussion of migrations and navigation within Polynesia. It would, therefore, seem to be in order to try to make clear what are facts and what are only hypotheses.

2. *Analysis of method*

(1) Horizon stars

The account of the basis gives unambiguous evidence of the fact that the course was steered by means of stars low on the horizon (horizon stars). This was done by keeping the bow of the canoe directed towards a rising or setting star, whose azimuth coincided with the course to the destination. In other words, one steered towards a star which rose (or set) over the island one wished to reach. However, the bearing of the star is not constant but changes continuously according to the changing altitude of the star. The course to be steered, and the bearing to the star will therefore coincide for a limited period of time only. For how long, then, can the canoe be steered by one particular horizon star? This depends on the declination of the star (its distance from the celestial equator), the latitude of the navigator and the desired accuracy of navigation.

On the equator the navigator can follow a given star between 1 and $1\frac{1}{2}$ hours for one-degree accuracy, between $1\frac{3}{4}$ and $2\frac{1}{2}$ hours for three-degrees accuracy (Frankel, 1962, p. 42).

There is, however, an exception from this. If the navigator is on the equator and steers a course due east or west, the bearing to stars which rise due east and set due west (declination 0°) will coincide with the course the whole time. Theoretically speaking, it would therefore be possible to steer by such stars as long as they were visible. In practice, however, it is not quite as simple as that, because the higher a star is in the sky the more difficult it is to steer by. So, with the exception of this special case the navigator has to shift from one steering star to another at about hourly intervals in order to be able to keep dead on course. Only stars which rise at the same or at about the same point on the horizon (have the same declination) can, of course, be used. If it is dark for ten to twelve hours out of the twenty-four then a corresponding number of steering stars will be needed. However, the same stars can only be used during part of the year because the apparent positions of the stars are constantly changing. If sea voyages are embarked on at widely different times of the year, then twice as many steering stars, or close on twenty-four, would have to be known in connection with any one destination.

As has previously been shown, we have reliable supporting evidence from such places as Tikopia, Samoa and Buka that the Polynesians used the method of steering by a succession of stars rising or setting over the destination. During one night's sailing (paddling) nine stars were used on Tikopia and ten on Buka. This corresponds quite well to the theoretically required number of steering stars.

During shorter voyages, or where there was no need for great accuracy in navigation, for example, if the destination was of large extent, then it was possible to manage with fewer guiding stars.

It is also obvious that the Polynesians must have known a large number of stars, since each of the different destinations to which they voyaged demanded its own combination of steering stars.

In order to be quite sure that the canoe was on course the navigator steered, when possible, by a star ahead as well as one astern. According to Krämer the course line was indicated by a line between these two stars and the canoe was on this track when the stars were dead ahead and astern. If this was not the case the canoe was off course and the necessary correction was made. Such a procedure is inconceivable. In the first place, the two horizon stars on which the canoe lined up must have an azimuth difference of exactly 180° . It is very rare indeed to find stars which offer this combination. To take an accurate bearing precision instruments are required and the Polynesians did not possess

these. In the second place, before a change in the bearing of the stars, due to a deviation from the course line, becomes noticeable, the canoe will be so far off its track that the navigator will probably already have realized from other factors that his navigation is at fault. In addition to this, an interval of almost 24 hours has to elapse before it is once again possible to check the course with the help of these stars. Guiding stars ahead and astern merely made it easier for the Polynesian navigator to steer the course. They could not be used as a means of determining deviations from the course to be made good.

The method requires that stars with the same or almost the same declination be selected (that is to say, stars which rise and set at the same points on the horizon). It is, however, rare to find a sufficient number of such stars with the necessary magnitude in the same sector of the sky. Thus it is probable that the navigator also had to steer by rising and setting stars whose azimuth differed somewhat from the true course to the destination. It would then be necessary to make a certain correction, that is to say, the navigator would have to ensure that the bow of the canoe was kept a certain number of degrees to port or starboard of such a guiding star. Naturally the steering would then be less precise.

With changes in latitude the bearing of a horizon star also changes. This fact was of no importance to the Polynesian navigator. He steered all the time towards stars which he knew rose or set over the destination and consequently the canoe moved along a great circle, which is the shortest distance between two points on the surface of the globe. From this point of view the method may be said to be perfect. Accuracy in navigation according to the horizon star method is also dependent on leeway and set with currents, as well as on the ability of the helmsman.

When out of sight of land it is impossible to determine without instruments the set and drift of the ocean current and its effect on the canoe. It is possible to make a reasonably good approximation of leeway, but the accuracy of the correction will depend entirely on the navigator's experience, while the extent of the steering error will depend on the skill of the helmsman, the weather and the visibility of the heavenly bodies.

The bearing of the rising and setting stars is the same irrespective of where the navigator happens to be on a parallel of latitude. Navigation by means of horizon stars will not, therefore, provide any information as to the change in longitude during the voyage. This is illustrated in a simplified version in Fig. 4.

A canoe sails from A to M guided by the horizon star S, which when seen from A is in line with M. Provided there is no steering error and

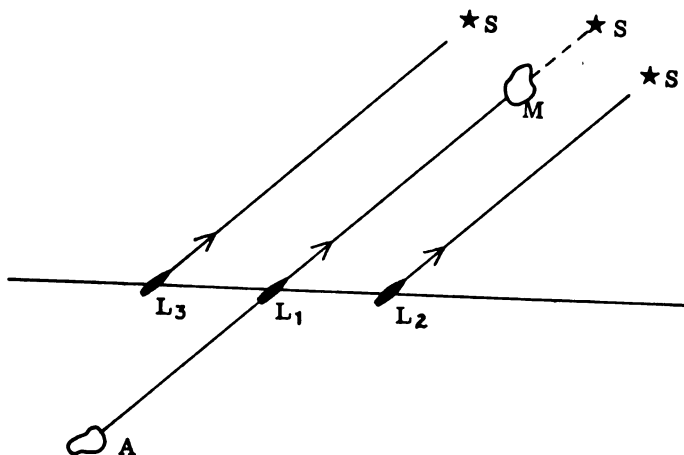


Fig. 4. Steering by a horizon star.

no drift the canoe will reach its destination by aiming straight for S, and for successive horizon stars having the same path.

However, during the voyage the canoe is subjected to drift owing to wind and ocean current, as well as steering error, and these lead the canoe to deviate from the course line AM. This deviation increases as the voyage continues. If, as a result, the canoe is set to L_2 or L_3 , M will no longer be in line with the star S, and this means that the canoe will miss its destination. In other words, the longitudinal error L_1-L_2 or L_1-L_3 cannot be perceived by the navigator.

If the destination is not of large extent the problem of determining longitude will be of fundamental importance right from the start of any voyage involving a course north or south. After only a short distance the question will arise: Have drift and steering errors so affected the position of the canoe that the destination is now to port or starboard of the course line? As the navigator was unable to determine the longitude he could not answer this question.

When sailing on a course east or west a correct determination of longitude was not of decisive importance, until the canoe was approaching its destination. At his departure the navigator knew whether the destination lay to the east or the west and then with the help of the horizon stars steered the known course for the time his experience indicated to be needed for the voyage. An easterly or a westerly displacement would then mean that the canoe arrived at its destination sooner or later than expected, while a northerly or southerly displacement meant that the

canoe was steering to the north or south of its destination. In order to correct the last-mentioned error the navigator had to know how to determine his latitude, and this could not be done by means of horizon stars.

The two examples discussed here, sailing on north-south or east-west courses, are no more than simplified special cases intended to illustrate the basic navigational problems. As a rule navigation calls for ability to determine both latitude and longitude and not just one of them.

The horizon star method involved only keeping on course with the help of stars. It did not permit any determination of the deviation from the course line during the voyage, nor did it afford any means of fixing the position, latitude and longitude. So, it was only at the beginning of the voyage that the navigator could be sure that he was steering a course which coincided with the intended track. In principle this method can be described as "dead reckoning". In other words, when out of sight of land the position was determined by means of an estimate of the course and distance made good.

For the reasons set out here, navigation by means of horizon stars is regarded as very inaccurate for voyages over distances which entail sailing for many days or weeks. Account must also be taken of the fact that navigation might be made more difficult by unfavourable winds and bad weather, which temporarily obscured the steering stars, thus making it harder to keep on course.

As the horizon-star method is generally regarded as inadequate as a means of ensuring a reasonable margin of accuracy when navigating to and fro over great distances, it cannot be used to confirm the theory that the Polynesians maintained more or less regular contacts between distant islands or island groups. Some supporters of this theory have put forward various hypothetical navigational methods, which, if they had been used by the Polynesians, would have increased considerably the possibility of accomplishing two-way voyages over long distances. Because the hypotheses provide a much desired explanation of a difficult problem they have been eagerly accepted by many archaeologists and anthropologists, who sometimes refer to these navigational methods as if they had in fact been used by the Polynesians. Forgetting that these methods are purely hypothetical, they have sometimes stated quite categorically that "it is known that the Polynesians navigated in this way". The methods I am referring to here embrace navigation by "zenith stars" and "latitude sailing", which involve making a landfall solely by means of a determination of the latitude. Although these methods do not really belong in a survey of Polynesian navigation it has been considered desirable to examine them, since they are often mentioned in the debate about sea voyages within Polynesia.

(2) Zenith star

When using this method the navigator must know which stars pass through the zenith of the destination. At departure from his own island he sets course by the star that he knows to be in the zenith of the target at that moment. (The declination of the zenith star, its angular distance from the celestial equator, is equal to the latitude of the destination. Places with the same latitude have the same zenith stars.) Since the star is only momentarily within the zenith of the target in its apparent motion from east to west it is not possible to use it as a steering star except for a very limited time. However, it is followed by other stars with the same declination, and these pass in succession through the zenith of the destination. As they do so the navigator successively resets his course by shifting over to new zenith stars.

Apart from one fundamental exception, the method can be said to correspond to some extent to navigation by means of horizon stars. In one case the steering is done by following stars which rise or set over the destination, in the other by following stars which pass through its zenith.

The method requires the navigator to know the precise times at which the various stars are in the zenith of the destination, because it is only then that it is possible to steer a true course with the help of these stars (except in the case of courses due north-south and due east-west at the equator). Before the zenith passage they indicate a course to the east of the target, after the passage a course to the west. Thus the navigator must know what the time is in the place he wants to reach. But he has no timepiece.

If, for instance, the canoe is 1000 miles from its destination, the altitude of the steering star (the zenith star) is 75° , while at a distance of 240 miles it is 86° . As it is extremely difficult to steer a course by following stars which are so high above the horizon, the cumulative steering error will be considerable, even during short voyages. (Cf. Frankel, 1962, p. 44.)

Reche (1926, 1927) and Gatty (1958, p. 40) are among those who have advanced the theory of the zenith star method. None of them, however, has presented any evidence in support of this theory.

The zenith star method has been subjected to a detailed theoretical analysis by Frankel (1962, pp. 43—45), who arrives at the conclusion that it calls for astronomical knowledge and aids (including timepieces) of such a kind as to exclude altogether the possibility that it could have been employed by Polynesian navigators. There is no gainsaying these conclusions, and it would also seem unlikely that there remain many people who would seriously maintain that this hypothetical method was ever used within Polynesia.

(3) Latitude sailing

Latitude sailing (parallel sailing) means that the navigator sets his course, not towards the destination, but so much to the east (or west) of it that he knows with certainty that he will reach the parallel of latitude through the destination, well to the east (or west) of his target. Thereafter he changes course and sails due west (or east) along this parallel until he reaches his destination. This method enables the navigator to compensate right from the time of departure for the unknown and indeterminable longitudinal displacement of the canoe during the voyage. But this also requires the navigator to set course for a point a considerable distance to one side of the destination, so that, when the parallel of latitude is reached, he is not in any doubt as to whether the island he is heading for lies to the east or the west.

The latitude method demands of the navigator that he should be able to decide when he has reached the same latitude as his destination, and also that he should know how to steer a course due east-west. On the other hand this method renders unnecessary a determination of the longitude. The latitude method has been known for close on a thousand years, and has been practised by Arabs and Europeans right up to the present century. It did not pass out of common use until the invention of the chronometer provided the navigator with a reliable means of measuring time which made accurate determinations of longitude possible. The theory that the Polynesians used latitude sailing on their long ocean voyages has been advanced by many writers, including Rodman (1927, pp. 867—871), Makemson (1941, pp. 13—14), Gatty (1958, p. 41) and Frankel (1962, pp. 45—46). The reason that it was once proposed as a Polynesian method of navigation was that it explained how the Polynesians were able to accomplish the sea voyage, about 2200 nautical miles, between Tahiti and Hawaii and back (Fig. 5, p. 37). For those who wished to show that these two islands maintained a certain contact, and that this was not largely due to chance, it was necessary to suggest some navigational method which would have afforded a reasonably good chance of making such long voyages possible. The latitude method was the answer.

(a) *Determination of latitude*

As already noted, the latitude method requires an ability to decide when the parallel of latitude through the destination has been reached. This is assumed to have been done in the following way. The Polynesian navigator had to know before departure which stars passed through the zenith of the destination. Contrary to his procedure when using the

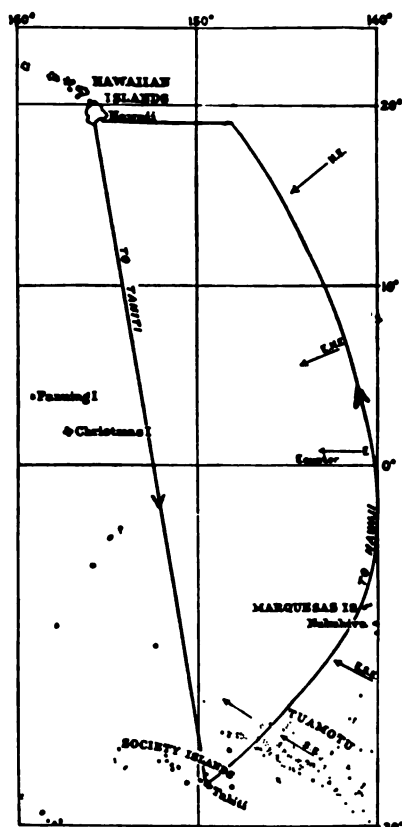


Fig. 5. Sailing route Tahiti—Hawaii (after Rodman, 1927).

zenith star method he did not set his course towards a zenith star, and consequently did not need to know the time of the zenith passage. Instead he steered by some other star, for example a horizon star, well to the east (or west) of his destination. When he had reached the parallel of latitude of his destination its zenith star also passed through his own zenith and the course could then be changed to due west (or east) and the canoe steered towards its target. (Cf. Fig. 5.)

The determination of latitude by means of a zenith star requires the observer to be able to decide with great precision when the star reaches his zenith. An error of 1° in altitude means that the navigator will have an error of 60 miles in latitude. Certain writers, among them Gatty (1958, p. 41) and Frankel (1962, p. 43), maintain that it is relatively easy to determine without instruments when a star is within one degree of the observer's zenith. The navigator points straight up in the air, turns round slowly and in this way obtains a fairly accurate determination of

the zenith point. Hilder, who has long experience of sailing in the Pacific, including voyages in Polynesian canoes, considers that this is "just fanciful nonsense". His view is that even when standing on firm ground an observer who uses this method is fortunate if he is right to within 5° ; from the deck of a canoe at sea the error could quite easily be as much as 10° , that is to say, 600 miles (1963*b*, p. 189). David Lewis, an experienced long-distance voyager, sailed a catamaran in 1965 from Tahiti to New Zealand via Rarotonga without the help of instruments, in order to test the reliability of the supposed Polynesian methods of navigation. Towards the end of his voyage he had become so adept that his margin of error when determining the zenith star did not exceed $12'$, equivalent to 12 miles, a degree of precision so astonishing that one is forced to wonder if a certain amount of luck was not also involved. (1966*a*, p. 165, and 1966*b*, p. 93). Obviously the accuracy of measurement is also dependent on prevailing weather and the stability of the observing platform. The heavier the sea, the poorer the values; the smoother the sea, the better the values. (The discussion here is, however, of theoretical interest only, since there is nothing to suggest that the Polynesians did in fact fix their latitude by observing a zenith star.)

Rodman has advanced another theory concerning the way in which the Polynesians determined latitude (1927, pp. 871—872). According to him it was done by observing Polaris. This star is located in the immediate vicinity of the north celestial pole and its height above the horizon is therefore very nearly the same as the observer's latitude. At the equator Polaris is on the horizon and it cannot be seen in the southern hemisphere, which is why the Polynesian could only use it as a navigational star north of the equator, that is to say for sea voyages to Hawaii, for example. The latitude of Hawaii is about 19° N, so they knew they had reached this latitude when the measured altitude of Polaris was found to be 19° .

However, a thousand years ago, one of the supposed approximate times of Hawaii's colonization, Polaris was not at the north celestial pole but about 5° from it. Consequently it was not "fixed", but described a path round the pole. It is hardly feasible that the Polynesians could observe and allow for this motion, which is so slight that it is difficult to determine it without instruments. (Polaris was called by them *Kiopaa*, which means immovable.) The determination of latitude by means of Polaris could therefore have led to an error of up to about 300 miles.

Latitude can also be determined by observation of circumpolar stars (that is to say, stars whose orbits at the navigator's latitude are always above the horizon) and when the stars are on the meridian. In the last-mentioned cases observation is possible only at dusk and dawn. At other

times during the night the horizon is too dark to allow any measuring of altitude. However, since there is nothing to suggest that the Polynesians were able to determine latitude in the ways indicated, it is not necessary to give more details of these methods.

Is there any support for the view that the Polynesians determined their latitude by means of zenith stars, by Polaris or in some other way? Makemson claims to have found some evidence as far as the zenith star is concerned, and as her conclusions have been uncritically accepted by many people they have given rise to the belief that it has now been incontrovertibly settled that the Polynesians employed latitude sailing through observation of a zenith star. Strangely enough, Makemson's interpretation of the sources on which she bases her views has not been questioned. For this reason it is desirable to examine her arguments more closely in order to see to what extent her conclusions can be considered tenable.

"In addition to those navigating stars whose positions near the horizon gave the desired great circle course, another class of stars was used for determining when the vessel had arrived in the latitude of its destination. Kepelino, a gifted Hawaiian scholar, characterized navigating stars as '*those which are suspended in turn over each land, as Hoku-lei over Hawaii*'.

The Polynesians had thus discovered that any star which passes through the zenith of a certain island also traverses the zeniths of all other points in the same latitude; likewise that all other stars of the same declination and diurnal motion as the given star—or, in their words, which rise from the same pit on the horizon—must also pass through the zenith of the same island.

Thus the mariner travelling north or south on the earth knew when he had arrived at the latitude of his destination by noting when a particular star passed overhead during the night." (1941, pp. 13—14.)

Hoku-lei (Alderbaran?) has a declination of 16° N and passes about 3° — 4° south of Hawaii's zenith. Therefore, Makemson considers, it can be used to determine when one has reached the latitude of Hawaii if one compensates for this difference. The Polynesian navigator would, in other words, determine when the zenith distance of Alderbaran was 3° — 4° , corresponding to an altitude of 87° — 86° . In A.D. 1000 Aldebaran's declination was about 14° N, which means a zenith distance at the latitude of Hawaii of about 4° — 5° . However, Makemson has quoted only part of what Kepelino said. If one reads the whole passage one quite soon finds good reason to adopt a totally different interpretation.

"The stars that act as guides to land are those that rise over each land, like

the Hoku-lea that rise over the Hawaiian islands *and the Hoku-kea over the Tahitian, and so forth*" (Beckwith, 1932, p. 82; my italics).

Hoku-kea is the Southern Cross. We cannot be sure which star *Hoku-lea* stands for, but it could be Arcturus. Makemson considers that *Hoku-lea* should instead be *Hoku-lei*, possibly Aldebaran.

The final portion of the quotation from Kepelino which links the Southern Cross with Tahiti is not included by Makemson, and this is understandable since it refutes her argument. The Southern Cross has a declination of about 60° S while Tahiti's latitude is about 17° S. Thus this constellation can never pass Tahiti's zenith and consequently cannot have been used to determine Tahiti's latitude.

Since, according to Kepelino, Aldebaran (?) and the Southern Cross had similar functions as navigational stars, both of them would have been used as zenith stars for the determination of latitude, if Makemson's hypothesis had been correct. As we now see, this was impossible in the case of the Southern Cross. The conclusions drawn by Makemson cannot, therefore, be correct. They are very doubtful on other grounds also. Kepelino states that the stars "rise over each land". It is difficult to see how this can be linked with a zenith passage. Moreover, the identification of Aldebaran made by Makemson in another connection is very doubtful indeed.

What the tradition actually tells us is simply that the navigator steered by certain selected stars which rose over certain specific islands. In other words, they navigated by horizon stars, a method which, as is evident from the foregoing, is convincingly verified from other quarters within Polynesia.

Consequently, it might appear superfluous to continue the analysis of the latitude method by considering the next phase of this, parallel sailing, which involves keeping the canoe steadily on a true east-west course. However, as the steering of this course is associated not only with this method but is a navigational requirement of general application, it may be worth while examining in more detail the extent to which the Polynesians were in a position to keep to such a course by means of astronomy.

(b) *Parallel sailing*

Once the canoe had reached the latitude of its destination it would follow an east-west course. This can be done by steering by stars whose declination is zero (their paths coincide with the equator). Only such stars indicate true east-west and they do so only when rising and setting (except on the equator).

Frankel has shown that to an observer at, for example 5° latitude an equator star deviates 3° from true east-west on reaching an altitude of 30° ; to an observer at 15° latitude the deviation would be 8° . The further away from the equator the observer is located, the more rapidly the azimuth of the equator stars changes and the shorter is the period during which they can serve as steering stars. At 15° latitude the azimuth changes 4° during the first hour after rising, at 5° latitude the change is only 1° . (Cf. Frankel, 1962, p. 45.)

It seems very doubtful whether the Polynesians possessed such a detailed knowledge of the motions and the paths of the equator stars as to be able to steer a course east-west accurately by means of them. It is conceivable, however, that north of the equator such a course could be steered approximately by keeping Polaris abeam.

(c) *Measuring altitude*

Irrespective of which of the above-mentioned methods of determining latitude is employed the altitude of the heavenly body must be ascertained. The western navigator measures the altitude with a sextant. Had the Polynesian navigator anything equivalent to this? H. Rodman, the American admiral, thought that he had such an equivalent in the form of the "sacred calabash", presented in a naval journal (1927, pp. 867—872).

According to Rodman the calabash was used during sea voyages from Tahiti to Hawaii. By observing the altitude of Polaris with its aid the navigator determined when the canoe had reached the parallel of latitude through Hawaii. The calabash, cylindrical in shape, was three feet high and had four holes bored at right angles to the longitudinal axis just under the rim. When measuring altitude the calabash was filled with water right up to the holes; the observer looked through one of these holes and when he saw that Polaris touched the rim of the calabash opposite to the hole he knew he had reached the latitude of Hawaii. The angle between the rim and the holes was 19° and this was equal to the desired latitude.

Rodman's article aroused great interest and his "sacred calabash", which was included in the collection of Bishop Museum, was examined by a museum official. The result, which was published by J. Stokes (1928, pp. 85—87), showed that the calabash was neither sacred nor a calabash; instead it was the travelling trunk of a Hawaiian chief and had been used for the storage of clothing and valuables. Moreover, Rodman's description was not accurate; for instance, instead of there being only one row of holes there were ten groups, each containing three

perforations through which strings had been passed to secure the lid of the wooden cylinder. The maximum angle that could be measured between holes and rim was 11.5° , not 19° . Consequently the "calabash" could not have been used in the way stated by Rodman. Also, when filled with water up to the level of the bottom row of holes the cylinder weighed nearly 100 lb, and Stokes expressed strong doubts concerning the practicability of using such an unwieldy object as a sextant, especially considering how difficult it would have been in the heavy seas of the trade-wind regions to hold it in a vertical position with the help of the internal water level. Stokes said that he would welcome Rodman's comments on these points, but no further information on the "sacred calabash" was forthcoming.

One has no hesitation in agreeing with Stokes, who doubts that the "sacred calabash" could have been a particularly suitable instrument for measuring altitude. It is possible to measure the vertical angle in a much simpler yet reasonable accurate way with the extended fingers of the outstretched hand. An experienced observer can estimate the angle to within one or two degrees. (Collinder, 1943, p. 93.)

In spite of the fact that all the evidence suggests that the "sacred calabash" was never used by the Polynesians and that it has long been considered ready to be consigned to the ethnographical limbo, modified versions of it still keep cropping up when Polynesian navigation is being discussed. (Cf. *JPS*, 1964, pp. 72—74.) It is for this reason only that the "sacred calabash" is mentioned in this essay.

Another strange theory about Polynesian aids to astronomical navigation has been presented in a yachting magazine (Te Kupe Rangi, 1965, pp. 72—73.) The writer concerned maintains that on the Maori canoe the sternpost constituted a "horizontal and vertical sextant", while carvings on the prow represented a "nautical almanac and sun tables". Any factual basis that might have existed for these astonishing claims is not supplied, however, and one is forced to conclude that the author is possessed of a particularly vivid imagination.

In conclusion attention should be drawn to the fact that there is a complete absence of evidence suggesting that the Polynesians utilized or had need of any form of instrument for measuring altitude.

(4) "Dreigestirne"

Krämer has not supplied any information which can explain how these three stars were used and how the method worked in practice. The basic data are much too scanty to allow a realistic analysis of method. In spite of this the German ethnographer, E. Reche, has made an

extremely theoretical and rather complicated analysis (1926, pp. 50—62; 1927, pp. 214—219 and pp. 266—271). However, as he proceeds from premises which do not agree with the facts given by Krämer (for example, he turns the three stars in a straight line into a triangle of stars) and as his argument in other respects appears very doubtful, too much credence ought not to be attached to his speculations. For this reason Reche's analysis has not been dealt with here.

3. *Determination of direction*

It is of vital importance to a navigator to be able to fix the cardinal points of the compass (N, S, E, W) when setting his course. These points can be determined by means of observations of the sun and certain stars (constellations).

(a) *Determination of direction by observing the sun*

When the sun is on the meridian it indicates true north-south. It is possible that by observing the sun the Polynesians knew how to determine this direction. We have no proof of this, however.

In everyday speech we usually say that the sun rises in the east and sets in the west. Strictly speaking, however, this is the case on only two occasions during the year, at the vernal and autumnal equinoxes, when the sun's declination is zero (its path coincides with the celestial equator). Apart from this the azimuth of the rising and setting sun varies with respect to its declination and the latitude of the observer. At the equator this variation amounts to $\pm 23.5^\circ$. If the rising or the setting sun is to be a reliable indicator of direction it is necessary to know and to be able to measure day by day the magnitude of the deviation of its azimuth from due east-west. If the requirements concerning accuracy are lowered and the deviation is instead determined once every ten days, the error in direction will amount to a maximum of about 4° . This happens at the equinoxes when the azimuth change is fastest. At the time of the solstices this change occurs slowly and the error in the direction obtained by determining the azimuth at ten-day intervals is, for all practical purposes, negligible. As the Polynesians closely observed the sun, it is probable that they also knew that the sun's azimuth changed at a varying rate. To achieve a satisfactory degree of accuracy when checking the course by means of the bearing of the rising or setting sun, the navigator must necessarily have had access to some form of memorized table of the changes in the sun's azimuth. Such a set of tables would in general have been valid for the whole of Polynesia apart from New Zealand, because

the tabulated bearings would have given the navigator a maximum error of about 1.5° when changing latitude. To this, of course, there has to be added the error in bearing obtained if the determination of the azimuth was performed at intervals longer than one day.

Since it is known that the Polynesians navigated by the sun, though the exact method is unknown, it might be of interest to recapitulate here what a scholar who is often quoted by anthropologists has to say on this point:

“When the sun rose, he (i.e. the Polynesian navigator) relied on its position throughout the day. Thus it is clear that he was familiar with the diurnal motion of the sun in the various seasons and knew how to find the compass directions from its altitude and azimuth at any time of day” (Makemson, 1939*b*, p. 5).

This statement is very misleading indeed. As a matter of fact there is nothing in the traditions, monographs, descriptions of voyages, etc., that could support the hypothesis that the Polynesians were able, at any time of the day, to check their course with the help of the known direction to the sun. This is no more than a hypothesis, but it has been presented in such a way as to convey the impression that it is a fact. Makemson credits the navigator with the ability to determine the azimuth of the sun at any time by observing its altitude, but this would have required him to memorize such an enormous quantity of data that we must regard it as out of the question, even for such an acknowledged memory expert as the Polynesian. In addition to this, he lacked the means of performing the precise measurements of the altitude that would have been essential. The passage quoted may serve as an example of the way in which misconceptions concerning Polynesian navigation can be accepted and spread.

Consequently, the information at our disposal does not justify the drawing of any definite conclusions concerning the way in which the Polynesians navigated by the sun. However, if we compare the situation in Polynesia with that obtaining in Micronesia, about which we know a good deal more, it does seem possible that the Polynesian navigator:

was able to determine north and south when the sun was on the meridian,

knew the true direction to the sun at sunrise and sunset at certain time intervals and in this way was able to check the course on these occasions,

during the remaining part of the day was able to keep only approximately on course with the help of the sun.

It has been shown earlier that the path of the sun was closely observed

within the Polynesian archipelagoes, but that these observations apparently were connected more with economic and ceremonial activities than with navigation. One probable consequence of this is that in the Polynesian names for the points of the compass it is rare to find any reference to the sun. Such references are found in Hawaii, however, where the following terms, among others, are used for east and west (Malo, 1951, pp. 9—10).

east: *Kukulu hikina* = The pillar of the sunrise

Ka la hiki = The sun arrived

west: *Kukulu komohana* = The pillar of the sunset

Ka la kau = The sun lodged

The word *kukulu* (pillar) is also found in the terms for north—*kukulu akau* (the pillar of the right hand)—and south—*kukulu hema* (the pillar of the left hand). The word refers to the pillars which, according to Hawaiian cosmology, supported the dome of heaven at the four cardinal points. According to Kepelino these terms are not original, but were introduced later (Beckwith, 1932, p. 78).

Corresponding information concerning the universe is to be found among certain Maori and here it is also reflected in the terms for the cardinal points, in which is included the word *toko* (pillar). This word, however, is associated with the winds and not with the heavenly bodies. (Best, 1923*b*, pp. 65—66; ed. *JPS*, 1926, pp. 40—42).

(b) *Determination of direction by observing the stars*

In Hawaii NORTH was determined by observing Polaris, *Kiopaa* (the Immovable). The word for north, however, was *koolau*, which is the same as the Tahitian *toerau*. Thus the original term for north was retained after the islands were colonized, despite the fact that in this case there was a fixed point, *Kiopaa*, by which to determine direction and it might therefore have been expected that the name of this star would become the term for north.

As mentioned above, Polaris was about 5° from the north celestial pole 1000 years ago, and so the course error might have been of this magnitude when this star was used.

Although Polaris is visible only north of the equator and consequently cannot be seen from Tahiti (latitude 17° S), there is nevertheless a local term for this star here. According to Henry it is called *Ana-hia* (Aster-above) and it is "the pillar to fish by, in the boundary of the sky" (1907, p. 103). As in Hawaii and in New Zealand, there prevailed on Tahiti the belief that the dome of heaven was supported by pillars, though

here the number was assumed to be seven or ten instead of four. The ten pillars were named after stars, but they did not form part of any directional system. Whether the fact that one of the pillars was named after Polaris is to be interpreted as evidence that Tahitian seafarers once embarked on ocean voyages north of the equator (perhaps to Hawaii, where Polaris is visible) seems very doubtful. It is possible that the name was borrowed at a later date, but against this it could be argued that the conception of the structure of the universe is very old, in all probability dating from the pre-European era. For this reason it seems somewhat unlikely that a pillar in the system should have changed its name and have been named after a star which was invisible to the Tahitians and consequently could play no part in this system. It is also conceivable that the name of this pillar is a folk-memory from a time before the migrations to the Pacific Ocean, when the Tahitians inhabited a region north of the equator.

According to Kepelino (Beckwith, 1932, p. 80), SOUTH was determined in Hawaii, and probably also in Samoa, by observing the Southern Cross. South was called *kona*, which is the same as the Tahitian *tonga*. It should be noted, though, that the Cross indicates true south only when it is upright, that is to say, when it is on the meridian.

4. Summary

Opinions are divided concerning the accuracy of the navigational methods of the Polynesians. Suggs represents one school of thought, Sharp another. The former is clearly of the view that the Polynesians had precise methods (1960, p. 78). The latter maintains that the Polynesians did not possess the necessary knowledge and means to evolve such methods (1963, p. 53).

Sea voyages over great distances cannot be accomplished successfully without some form of astronomical navigation, especially if the destination is of limited extent, as is often the case within Polynesia. Thus the vital question concerning Polynesian navigation is: What methods of astronomical navigation were used and how accurate were they? In the foregoing the methods, actual and hypothetical, have been described and analysed. They may be summarized as follows.

(a) Navigation was performed by means of HORIZON STARS. The method indicated only the course. It did not afford any possibility of determining latitude and longitude and so did not provide any means of estimating the displacement of the canoe due to current and leeway. As a result, it was only at departure that the course being steered could with certainty be regarded as correct. The angular difference between

course steered and course made good is dependent on currents, leeway and steering error. Leeway and steering error could to some extent be compensated for by an experienced navigator. The set and drift of currents, on the other hand, could only be judged and allowed for with sufficient accuracy when land was in sight.

The method was unreliable, as the navigator could not estimate how much his canoe was set off track when he was sailing over great distances in the open sea.

(b) It is possible that navigation was carried out by using **THREE STARS** ("DREIGESTIRNE"). Nothing definite is known about this method. It is probable that, like the foregoing one, it merely indicated the course.

(c) Navigation by **ZENITH STAR** was not applied. The suggestion that it may have been is purely hypothetical. It can safely be assumed that the method required much too advanced astronomical knowledge for it to have been used by the Polynesians.

(d) It is unlikely that the navigational method used was **LATITUDE SAILING** (parallel sailing). Here again it is a matter of a suggestion based on pure hypothesis. It is known that the Polynesians were very conscientious "star gazers" and it is therefore probable that they were well acquainted with the way the appearance of the firmament changed with changes in latitude. We do not know whether they put this knowledge into practice and, if so, how. It is unlikely that the latitude could be determined by observing a zenith star, though north of the equator it is not impossible that Polaris could have been used for a determination of this kind. However, as Polaris was then several degrees from the pole the latitude reading would be only approximate. Latitude sailing compensates for errors in longitude resulting from the displacement of the canoe. The method can be reasonably accurate over great distances, provided the destination offers a wide target or rises high above the surface of the sea, and the navigator knows how to steer an east-west course. It has, therefore, been attributed to the Polynesians and used as an argument in support of the view that two-way voyages were accomplished between distant islands and island groups. If the island is small (for example, an atoll) the chances of missing it are, however, considerable. Theoretically speaking, it is possible that the Polynesians did navigate by this method, but as there is a complete absence of proof that this was the case it cannot be described, as it sometimes is, as one of their "exact methods".

(e) NORTH-SOUTH could probably be determined during the night by means of the Southern Cross, and possibly of some other stars, when they were on the meridian, as well as of Polaris north of the equator.

(f) NORTH-SOUTH could probably be determined during the daytime when the sun was on the meridian.

It is possible that the course could be checked at sunrise and sunset by reference to the known direction to the sun at these times. During the remaining hours of daylight it is improbable that the sun could be used for course checking, except to provide a rough approximation. It must be regarded as out of the question that the Polynesians could have possessed a sufficiently detailed knowledge of the sun's diurnal motion to admit of an accurate checking of the course. It is probable that during the daytime the canoe was kept on course chiefly with recourse to other aids (see below).

Consequently, navigation during the day afforded less precision than did night navigation. This led the German ethnographer Reche to arrive at some rather strange conclusions. When the dawn came the Polynesians lowered their sails and spent the day fishing and sleeping. Even a Polynesian must eat and sleep. When night fell they set sail again and continued their voyage, steering by the stars. (1927, p. 271.) Comment would seem to be superfluous.

(g) It is unlikely that the Polynesians possessed any kind of instrument for measuring altitude. There is no evidence at all on this point.

PILOTING

1. Landmarks

The stars were the principal navigational guides for the Polynesians during voyages over both short and long distances. But in time the course at the departure was set with the help of landmarks. These could be natural formations of various kinds or they could be artificial ranges erected to indicate the course to a neighbouring island that was out of sight and could not be reached in a night's sailing. When embarking on such a voyage it was advantageous to arrange the sailing so that landfall could be expected to be made at dawn. If the navigator missed his target he then had the whole day in which to search for it. For this reason the voyage started well before dusk and the canoe was kept on course by holding the landmarks astern as long as they were visible. When the marks had faded from sight the steering was carried out by reference to horizon stars. In this way it was possible to avoid the hazards of navigating by day, out of sight of land, with the help of the sun, swell and wind. If the destination was a low-lying island, which could not be sighted at a great distance from the canoe, it was obviously of particular importance to have accurate navigation.

The method of navigation by reference to landmarks was probably in general use throughout Polynesia and accounts supporting this view have come from a number of different sources.

John Williams, the missionary, discovered Rarotonga by setting course from Atiu by landmarks used by the islanders when sailing to Rarotonga, 120 miles distant (1840, p. 25).

When voyaging from Anaa, in the Tuamotu Archipelago, to Tahiti the canoes were pointed "with scrupulous exactness in the supposed direction, which was indicated by certain marks upon the land, and then launched into the sea" (Beechey, 1831, p. 169). It is probable that orientating the canoes in the direction of the destination prior to launching them was merely a part of some ceremony performed before departure, since if the purpose was purely navigational it would seem to be much more sensible to set them on course after launching instead of before. The distance between Anaa and Tahiti is about 240 miles, and the course was not set direct, but via Muihia, which lies between the two islands.

Similarly, landmarks were used for voyaging between Tikopia and Anuta, some 70 nautical miles distant (Firth, 1961, pp. 27—28; 1954, pp. 89—95).

If one is to believe Woodford it seems that the Polynesians, at least in the Ellice Islands, were not altogether unacquainted with the use of

a sort of "beacon". The island of Nukufatu lies about 35 miles from the island of Vaitapu. When the inhabitants of Nukufatu wanted to visit the neighbouring island they would light fires on two consecutive nights out on the reef. When they saw an answering fire reflected in the night sky over Vaitapu they set out early the following morning in their canoes. The fire on Vaitapu was kept burning every night until all the canoes had arrived. (1888, p. 352.) The short distance, some 35 miles, means that in good weather it would have been fairly easy to make the trip in one night or one day. An average speed of 3 knots would suffice.

Steering by means of leading marks meant that the voyage was along a frequently used route, where the course had been fixed on the basis of experience. We have no proof that the marks indicated a course which would compensate for the displacement of the canoe due to currents and leeway, but this seems plausible. Hence a leading line was of value only during the sailing season. At other periods of the year, when the currents and winds changed direction, a course steered by such marks would be more or less incorrect.

The known examples of navigation by means of landmarks indicate that they were used only for short voyages, where it was not necessary to be out of sight of land for more than about 24 hours. In popular parlance one could describe this as a Polynesian method for coasting. The canoes were not of the ocean-going type and were not equipped for long voyages. For this reason the Polynesians took every precaution to ensure that they steered a correct course, and chose a suitable wind and time for departure, so as not to be in danger of sailing past their destination. To do so could end in disaster. Obviously the leading marks were of no importance in sea voyages lasting several days. They could be seen for a relatively short time and so could not have much effect on the accuracy of the navigation.

2. Wind compass

(a) Construction

The stars afforded the Polynesians ample opportunities of determining direction. On the other hand, the situation during the hours of daylight was completely different. Then there were no heavenly bodies, apart from the sun, to guide them, and except when it was rising and setting, and possibly at the transit, the sun was a most unreliable indicator of direction. They became dependent on other aids for constructing a directional system which would enable them to continue steering, with satisfactory accuracy, the same course as that followed during the night

with the help of the stars. The Polynesians produced such a system, involving recourse to the wind. This system is generally known as the "wind compass".

The weather and wind conditions are relatively stable within large regions of the Pacific Ocean for the greater part of the year. The trade winds are the most characteristic feature. However, the direction of the wind is not uniform throughout this vast area; it varies with the latitude and, to some extent, with the longitude as well. South of the equator the south-east trade wind is the prevailing one. As it nears the equator it backs to become easterly and south of the latitude of Hawaii it becomes the north-east trade wind.

On the whole the trade wind north of the equator remains fairly constant during the northern winter, while south of the equator the trade wind is unsteady over large areas at this time of the year.

During the trade-wind season the winds do not blow constantly from the same direction, but weaken at times and shift direction, occasionally giving way to northerly and westerly winds, though the frequency of such winds is low.

Outside the trade-wind season proper the easterly winds can give way to strong gusty winds from the north and west, which can blow for considerable periods.

The trade winds are more stable within eastern and central Polynesia than within the western regions.

The typical weather of the trade-wind zone, which lies approximately between latitudes 20° N and 20° S, is fair with scattered showers and skies about half-covered with small cumulus clouds. The average strength of the trade winds is about Beaufort strength 4.

Between the trade winds and near the equator there is a belt of low pressure, the Doldrums. The characteristic weather pattern here is calm and light variable winds alternating with squalls, heavy rains and thunderstorms.

The foregoing very brief outline of the wind conditions within Polynesia is intended merely to provide a background to an understanding of the wind compass. The Polynesian sailing season was confined to the trade-wind period, when steady winds and good weather could be expected. It was these winds, which blow mainly from one general direction, that made it possible for the Polynesians to construct their wind compass and steer a day-time course in relation to the direction of the wind.

As a rule the number of directions shown on the Polynesian wind compass varied between twelve or sixteen and thirty-two. The directions were named after the winds. The system was not uniform, even within the same island group. "The same wind was often called by as many

names on the same island as there were capes and headlands along the coast of that island" (Emerson, in Malo, 1951, p. 15).

Nevertheless, the names of two winds are to be found in virtually every part of Polynesia, and they occur here and there in Melanesia, too. These names are *tonga* and *tokelau*, with variations in the spelling according to the dialect. However, the wind direction denoted by these names varies a great deal and as far as *tokelau* is concerned covers, in the main, directions within the two northern quadrants. In the case of *tonga* it seems to denote directions in the two southern quadrants, with the south-eastern one predominating. The names of adjacent compass points are often derived from these two terms. Neither *tonga* nor *tokelau* has been identified as referring primarily to the trade wind, which is what one would have expected in view of the fact that it blows relatively steadily from one quarter and so could have been used as a firm basis for the system. It is conceivable, however, that throughout the whole of Polynesia the two names were given a universal interpretation, which can tentatively be formulated as follows: When the prevailing wind was a *tonga* wind (easterly) it was suitable for voyages to the west, north and south, while the *tokelau* wind (westerly) was suitable for voyages to the east. For instance, within the Society Islands, the prevailing winds during December and January were *toerau*, predominantly from the north-west or west-north-west; "... this meant dark, cloudy, rainy weather; it was the only wind in which the people of the islands to leeward came to Tahiti in their canoes" (Williamson, 1933, p. 143). (Leeward in this case must be seen in relation to the south-east Trade.)

In Hawaii, when alluding to the Trade, north and south were called *iluna* (up) and *ilalo* (down) respectively (Malo, 1951, p. 9). The expressions up and down "... are used with reference to the prevailing trade winds. One is said to 'go up', when travelling against the wind, and to 'go down' when sailing before it". (Fornander, 1878, p. 18.)

The wind compass is not peculiar to Polynesia. Long before the present era began it was known and used in the Mediterranean, as well as elsewhere. Here, as in Polynesia, the system of direction was linked to the winds, since the winds bring the weather, and if the wind veered it could, for example, mean a noticeable change in the air temperature.

"It follows that the 'feel' of a wind gives a rough indication of direction. and it is not surprising that the names given to well-recognized winds are also used simply as direction names, and that a division of the compass of the horizon in terms of winds supplemented or even superseded that in terms of Sun and stars" (Taylor, 1956, p. 14).

The earliest wind compass in the western world was an eightfold direction system; this was succeeded by a twelfefold system, which was

later developed into a thirty-twofold one. It does not seem unlikely that a similar system also existed in India and China. The magnetic compass is likely to have been put into practical application for the first time in China, probably not before the 11th century, and it would appear to be quite certain that our present-day division of the compass card originated with the wind compass.

The Polynesian wind compass is therefore unlikely to be an imitation of the magnetic compass of the post-European period, but was probably brought from south-east Asia during the Polynesian migrations to the island world of the Pacific.

On the other hand, it may be doubted whether the descriptions we have of the Polynesian wind compasses give a complete picture of their original form and divisions. The records were made when the original art of navigation had already begun to sink into oblivion among the Polynesians and the magnetic compass had become known to them. It is, therefore, not impossible that in the course of time the wind compass has been distorted.

(b) *Reliability*

According to Gill, knowledge of the wind compass was of great importance to the navigator in the Hervey Islands. "In the olden times, great stress was laid on this knowledge for the purpose of fishing, and especially for their long voyages from group to group" (1876, p. 369). For navigational purposes the compass can only have been of value so long as there was a fixed reference point in relation to which it could be orientated. It is possible that this was done with the help of the sun. "The head of the winds is supposed to be in the east" (Gill, 1876, p. 320). When it was overcast, or when visibility was reduced, there was no such reference point and a shift in the wind direction could quite easily be overlooked.

Fog at sea is rare within Polynesia, but owing to what is known as "trade-wind haze" visibility can fall to less than 5 miles at times during the trade-wind season (*PIP* III, 1957, p. 41). Fog and reduced visibility were hazards that the Polynesian seafarers could not master. When this kind of weather was encountered it was easy to lose one's sense of direction and when several canoes were voyaging together they hove to in a group and waited until the visibility was restored to normal (Firth, 1954, p. 92). Generally speaking the wind was not a reliable indicator of direction in such weather conditions, as is evident from Mariner's description of a canoe voyage within the Tonga Islands, in which he himself took part. The canoe ran into fog and the Tongan

navigator continued to steer his course by the direction of the wind. Mariner, who had brought a compass, saw that the wind had veered, but the navigator did not notice this. The canoe was therefore on an incorrect course, which would have led them to miss their destination by a considerable margin. It was only after much persuasion that Mariner was able to induce the Tongans to alter course and steer in the direction he indicated by means of his compass. (Martin, 1818, pp. 48—50.)

It is apparent from this that the wind compass can be a most unreliable and misleading aid if reference points are absent. However, it would seem that when combined with other navigational methods the compass could have been of real value to the Polynesian navigator.

3. *Ocean swell*

Ocean swell in one form or another is present in virtually all stretches of open water of any size. It is the result of a wind, e.g. the trade wind, having blown from the same direction for a long period. The swell persists long after the wind that caused it has ceased to blow. Swell must not be confused with waves, which even a temporary wind can produce. When the wind changes direction the waves also changes direction accordingly, while the underlying swell remains unchanged.

The skilled Polynesian navigator could obtain much useful information by observing the prevailing swell. A change in its appearance and direction could be an indication of the direction to land, which could sometimes help the voyager to make a successful landfall. The course that was steered by night by reference to horizon stars was maintained by day by keeping the angle between the bow of the canoe and the direction of the swell unchanged.

The Spaniard Andia y Varela has given a detailed account of how the wind and swell were used as navigational aids for voyages between Tahiti and Raiatea.

“... he knows the direction in which his destination bears: he sees, also, whether he has the wind aft, or on one or other beam, or on the quarter, or is close-hauled; he knows further, whether there is a following sea, a head sea, a beam sea, or if it is on the bow or the quarter. He proceeds out of port with a knowledge of these (conditions), heads his vessel according to his calculation, and aided by the signs the sea and wind afford him, does his best to keep steadily on his course” (Corney, 1915, pp. 285—286).

The ocean swell, however, is not always a sure and clear aid to navigation. Hilder has described the difficulties facing a seafarer who seeks to interpret its patterns.

"One day at anchor off the western end of Washington Island I observed separate swells coming from four directions at once: north, south, west and south-east, the latter with the wind and sea. There may have been another from north-east, but the island blocked that direction. The resultant patterns in the ocean are really confused, and the amplitude of each swell series varies at times, sometimes stopping altogether for no discernible reason, and with no islands in the way" (1963*b*, p. 189).

OCEAN CURRENTS

(a) *Survey*

The north and south equatorial currents flow westwards across the Pacific Ocean under the influence of the north-east and south-east trade winds, respectively. The south equatorial current extends some distance north of the equator. These two currents are separated by the eastward setting counter-equatorial current, which, like the north equatorial current, lies north of the equator. The equatorial currents extend towards the poles up to about the 20th parallel. The strength of the trade wind diminishes the higher the latitude and in the same way the speed of the westbound currents is reduced. Consequently, near the equator the drift of the currents is greatest and their direction more constant.

The southern boundary of the north equatorial current lies at about latitude 8° N. The current flows mainly in directions varying between north-west and south-west, though it can also set in any other direction. The maximum speed of the current is about $1\frac{1}{2}$ knots, but in the eastern regions it seldom exceeds 1 knot.

The south equatorial current is stronger and more constant than the northern one. It flows mainly in directions varying between north-west and south-west, though on occasion it can set in any other direction. As a rule the current flows at a speed in excess of 1 knot and speeds between 2 and 3 knots are not unusual.

The boundaries of the equatorial counter-current are at times sharply defined, so that, in a short space of time, a ship on a northbound or a southbound course may pass from a westbound current to an eastbound one, or vice versa. The equatorial counter-current does not set eastward all the time, but, like the other two equatorial currents, can vary its direction very considerably. On average the current flows at a speed between 1 and 2 knots, irrespective of direction.

Local currents and tidal currents set in varying directions within the various island groups, but are as a rule stronger than those found in the open seas.

(b) *Determination of set and drift of the current*

Out of sight of land the set and drift of the ocean currents can be determined by astronomical or other observations which fix the position of the vessel during the voyage. Measurements of the current can also be carried out from a vessel lying at anchor; however, in the Pacific such measurements are usually not possible owing to the depth of the ocean bed.

During their ocean voyages the Polynesians were not able to determine their position and so it was not possible for them to decide whether there was a current and, if so, what was its set and drift.

The brief introduction given above makes it clear that the ocean currents may have a speed of 1 knot and more, and that they can flow in widely varying directions. A current of 1 knot across the course will set the canoe 24 miles off track in 24 hours. Consequently, a voyage lasting many days and nights could, in adverse conditions, involve a considerable error in navigation due to the current. It is, however, not impossible that, on shorter voyages to neighbouring islands, which did not entail sailing for more than a day or two, the Polynesians learnt from experience how to estimate and compensate for the expected current.

Elsdon Best has given certain details which suggest that the Maori tried to solve the problem of estimating the current.

“And the rope of the *mahe* (the anchor of the Maori canoe) of the bow, and that of the stern of the vessel were paid out in order to ascertain the aspect and direction of the ocean current, whether far below, or midway, or at the surface, whether astern, or ahead” (1923c, p. 211).

Best says this is in agreement with the information supplied to him verbally by a Maori, according to whom a stone tied to a rope was lowered into the water in order to find out the direction and speed of the current. “It was always desirable to voyage with an *au kume*, a favourable current.” (1923, p. 211.)

It is possible that the information given by Best refers not to a measurement of the direction of the ocean current, but to one of temporarily occurring surface currents. These may often be indicated by “channels” in the surface of the water, and their direction can be roughly estimated by paying out a line (say with a floating object attached) over the stern and observing the direction it deviates from the longitudinal axis of the canoe. When this is being done the speed must be low. A measurement of the direction of a homogeneous ocean current by means of the simple device mentioned here is impossible as long as the canoe is not at anchor.

The local currents and tidal currents could best be determined by observing the displacement of the canoe in relation to landmarks. Of course, these currents were of no importance during long sea voyages, except at departure and when making a landfall. The Polynesians were well acquainted with the fact that the tides were connected with the moon, and had names for their different phases.

The transition between warm and cold ocean currents can be observed fairly easily through the rapid change in the temperature and colour of the water. Gatty is of opinion that this was an important factor in

“primitive” navigation, and that it was essential for the seafarers to have a knowledge of the ocean currents and enough experience to identify them (1958, pp. 165—166). However, within Polynesia the currents are all warm, and so there cannot be any well-defined temperature boundary lines between them, although variations in temperature do exist. In the account in the tradition of a voyage from Samoa to Rarotonga there is a suggestion that this could possibly have played some part in navigation.

“Tangiia . . . on putting his hand into the sea to ascertain the set of the current, . . . was astonished to find the water hot . . . He at once put his canoe about and shortly after, on putting his hand into the water again, he was glad to find it had become cooler, and that his canoe was safe.” (Stair, 1895, p. 108.)

At first sight it might seem that the information derived from this tradition is without foundation in reality and ought therefore to be dismissed as valueless. Stair has pointed out, however, that submarine volcanic activity has been shown to exist in this part of the ocean and that this could have caused a rise in the temperature of the water. It cannot therefore be regarded as out of the question that the Polynesians might have been aware that such a phenomenon could be observed when navigating over the above-mentioned area and that this might lead them to make an approximate determination of the distance sailed.

In all probability, however, any observations that might possibly have been made of temperature changes were of minor importance as far as determination of position was concerned.

METEOROLOGY

Weather and wind are of great importance for a seafaring people, whose safety often depends on their ability to make reliable weather forecasts. Within Polynesia, with its relatively stable and seasonal weather conditions, the times for the beginning and ending of the trade wind and the onset of spells of bad weather were forecast by reference to the rising or setting of certain stars (*inter alia*, Buck, 1938, p. 415; Best, 1922*b*, p. 41). But it seems that local non-seasonal changes in the weather could also be predicted with considerable accuracy. According to Nordhoff the Polynesians retained this ability right down to our own times: "... the old fishermen have a truly profound knowledge of weather and winds. Though I have never been able to learn how they go about it, it is a fact that such men can predict the weather with an accuracy the meteorological department of any government might envy" (1930, p. 250).

At times the winds were associated with certain villages, which were credited with the ability to control them. This was connected with the geographical location of the villages. A village on the eastern side of the island controlled winds from the east, a village on the southern side winds from the south, and so on (Beaglehole, 1938, p. 21). Malinowski has supplied similar details from Trobriand (1960, p. 225).

Gill has given a description from the Hervey Islands of how this "control" was exercised. The meteorologist-priest predicted the weather with the help of a wind calabash, the interior of which symbolized the sky. Round the calabash there was a row of holes with plugs. These holes represented the openings at the horizon through which it was believed that the wind came. If the wind was not favourable for the sea voyage that was imminent, the priest drew the plug from the hole from which this wind was assumed to blow. Then he replaced the plug and in this way prevented the wind from getting out. He then continued with other plugs until he came to the hole out of which the desired wind would blow. This he left open as a command to the wind to blow steadily from that direction. As the priest was a skilled meteorologist and good at predicting the weather there was little risk of his "control" not succeeding. (1876, p. 321.)

Even though this description does not provide much detail about the way in which the Polynesians carried out meteorological observations, it is of some interest inasmuch as it shows that an intimate knowledge of wind and weather was not possessed by every individual, but was probably reserved to the priests, who consequently had a very important function to perform in deciding what would be the most appropriate

moment to embark upon a long sea voyage. In certain places the priest himself sailed with the canoe as adviser and weather forecaster. It may be that the sailors thought this the best way of ensuring that the priest would exercise due care when making his prophecies before departure. The profession had its occupational hazards; if a wrong prediction had been made, if the weather turned bad and the canoe was blown off course the priest might have to serve as a reserve food supply for the hungry crew. "On Funafuti (Ellice Islands) the priest, *vakatua*, chose the auspicious day for starting on a long voyage and in the event of the vessel missing her destination, he might suffer vengeance by being killed and eaten by the crew of starving castaways" (Hedley, 1896, p. 283).

It was not only the heavenly bodies, but also the appearance of cloud formations, the behaviour of plants and animals and other signs of nature which served as a guide to the meteorologist when he was preparing his forecast. Gill says that in the Hervey Islands the forecaster had "an unfailing natural indication of an approaching typhoon... the core of the true native banana is strangely twisted and contorted some weeks previous to a hurricane" (1876, p. 321). According to the same source, the phenomenon is caused by the increased humidity of the air and heat which accompany a cyclone. (The assertion that it was possible in this way to obtain several weeks' warning of an approaching cyclone seems improbable, however.)

As already mentioned, the sailing season was limited to the trade-wind period. If the destination lay to the east, that is to say, against the prevailing wind, it seems that, even on short voyages, the Polynesians generally avoided sailing into the Trade and instead waited until the wind was more favourable. Sailing eastwards during the trade-wind season was not, in fact, impossible, for now and then the trade winds are replaced by westerly winds which may blow for several days. These winds, however, can bring bad weather, rain and reduced visibility (*PIP* II, 1956, p. 34). In such conditions it was more difficult to navigate because the sky was often overcast and so there were no stars to steer by. According to Firth, when sailing from Tikopia to Anuta (some 70 miles north-east) the sailors would wait for a south-easterly wind, by which they could set course for the destination without needing to make allowance for leeway (1954, p. 91). Krämer has reported that the Samoans patiently waited several weeks for westerly winds when they were planning to sail to Manua, some 70 miles to the east (1903, p. 247). The same also applied to voyages between Fiji and Tonga (Pritchard, 1866, p. 383).

LANDFALL

As mentioned previously, the Polynesians tried as a rule so to time their sailing that landfall could be made during the hours of daylight, preferably at dawn. Given the uncertain navigational methods at their disposal there would otherwise have been a danger, even when making short voyages, that in the dark they might sail right past a destination which was only of limited size. During the hours of daylight the chances of sighting land at a distance were of course much better, and if land was not in sight, there were many other signs suggesting that it was near and indicating the direction to it.

How close, then, had the navigator to get to his target to have a fair chance of making a successful landfall? The question has been much discussed but since the conditions vary from case to case it is impossible to give a general answer. I therefore confine myself to mentioning below a few points which may serve as a basis on which to assess the problem of landfall.

1. Sighting distance

The distance from which land can be sighted depends on the height of the land above sea level, the observer's eye-level and the visibility. Normal atmospheric conditions are assumed in the cases which follow.

Experience shows that an atoll can be seen from the deck of a canoe at a distance of about 8 miles (Grimble, 1957, p. 53), and from the mast top at a distance of about 11 miles.

Below are set out the theoretical sighting distances in respect of some elevated islands. The observer is assumed to be on the deck of a canoe.

<i>Island</i>	<i>Max. altitude</i>	<i>Sighting distance</i>
Tahiti	approx. 2350 metres	approx. 95 miles
Fatu Hiva	960	62
Mangareva	440	44
Mangaia	170	30
Tongatabu	60	20

The distances stated do not agree in every respect with those which have been obtained in practice. Islands with high mountains cannot as a rule be seen from the distances given above, while low-lying islands can as a rule be sighted from distances greater than those calculated theoretically. Frankel has shown that for elevations below 600 metres

“the theory underestimates sight distance, while greater elevations cannot be seen from as far as predicted” (1962, p. 40).

2. *Clouds*

Clouds have a tendency to form and remain round mountain tops on hilly islands. These cloud formations can often stretch high above the peaks and give the impression of being stationary in relation to other clouds. Such apparently stationary clouds can indicate the existence of land from considerable distances, long before the island has come within sighting distance.

In one of the traditions of Kupe's voyage to New Zealand we are told: “When finally they beheld the clouds over the distant island, Kupe exclaimed, ‘There are some peculiar clouds hanging there in the distance; it surely is a point of land’” (Smith, 1914, p. 208). The phenomenon described in the tradition is so characteristic of New Zealand that it is even found in modern sailing directions: “There is a cloud with the ‘föhn’ wind known as the ‘föhn arch’, it forms high up above the mountains, with the apex generally towards the north-west, while to the south-eastward the sky is generally clear” (*The New Zealand Pilot*, 1958, p. 35).

But cloud formations above low-lying islands can also indicate the presence of land from a considerable distance. Grimble states that the upper portion of a cumulus cloud piled above such an island is bent towards the surface of the sea by some draught, probably caused by heat refraction from the island, and that this constituted “a true compass” on the occasions he himself observed the phenomenon (1924, p. 128).

3. *Reflection*

What are called “standing clouds” may form over an atoll. The reason for this is that the white coral sand reflects more heat than does the surrounding seawater, and that the sharp change in the temperature gradient can be sufficient to create suitable atmospheric conditions for the formation of cloud (Gatty, 1958, p. 84). The underside of such a cloud may, when conditions are favourable, have a greenish tint owing to the reflection of the green water in the shallow lagoon. It is claimed that this phenomenon can sometimes be observed long before the atoll is sighted. Buck has described how he observed such a reflection when bound for Anaa in the Tuamotu Archipelago. According to the captain of the schooner, the reason why the cloud reflection could be noticed over this particular atoll was that the water in Anaa's lagoon was shallower and greener than that in the lagoons of other atolls in the archipelago.

Buck does not say from what distance he saw the reflection; he only tells us that five hours later the schooner was alongside Anaa (1964, p. 186). The phenomenon is a characteristic feature of Anaa and is mentioned in the Admiralty Sailing Directions: "A curious effect, apparently mirage, is produced by this atoll in certain weather conditions; its shallow lagoon projects on to the clouds a beautifully clear-green reflection which can be seen at a great distance. In 1938, the French war vessel *Zélée* reported observing this phenomenon at daybreak, the reflection then being of a dirty greenish colour, but clearly defined" (*PIP* III, 1957, p. 109).

According to Makemson a similar reflection phenomenon has also been observed over Fanning Island from a distance of 25 miles (1939*b*, p. 19). Hilder, who has himself observed such reflections, says, however, that he has never been able to observe them from a distance greater than about 11 miles, that is to say, about the distance at which an atoll can be sighted with the naked eye from the mast top of a canoe (1963*b*, p. 189).

Cloud reflection is probably relatively rare, being dependent on the light and atmospheric conditions and confined to certain atolls possessing lagoons of the right depth and colour. It is probable that the Polynesians made use of this phenomenon when making landfall at certain islands, but it is unlikely to have been of any great importance in Polynesian navigation.

Another and more usual sign that land is near is the "loom" above an atoll, and this, says Grumble, is what the navigator looks out for. It is due to reflection of the glare of the tropical sun by the coral sand and the lagoon, resulting in a pale, shimmering pillar of light, which can be seen at a great distance, projecting upwards over the island. (1924, p. 128.)

4. *Special aids*

The presence of certain BIRD species out at sea has always been taken by seafarers as a sign that there is land in the vicinity. By making dawn and dusk observations of the direction in which they were flying it was possible to deduce where land lay.

Beechey mentions that in the Tuamotu Archipelago flocks of white and black terns out at sea were a fairly sure indication that land was near, and that they made their appearance at a distance of about 40 miles from their native island (1831, p. 195).

The navigator in the Gilbert Islands also keeps a lookout for birds. If he loses sight of them he knows that there is no land in the vicinity. When he returns from a long voyage and meets a flock of gulls he steers in the

direction in which they are flying, "for that way lies terra firma". (Grimble, 1924, p. 128.)

Like the Vikings, who took ravens with them on long sea voyages, the Polynesians are also said to have had winged pilots aboard. When they thought they were nearing land they released a bird. If it rose high in the air and disappeared over the ocean they steered in the direction it had taken, since they knew the bird had sighted land.

Many people believe that the Polynesians discovered the Hawaiian Islands and New Zealand by steering in the direction taken year after year by migrating birds arriving at or leaving the Society Islands.

Cartwright is among those who hold the view that the golden plover led the Polynesians from Tahiti to the Hawaiian Islands (1929, p. 109). This birds migrates every autumn from Alaska to Tahiti and other island in the south-eastern Polynesia, flying via the Aleutians, Hawaii, Fanning Island and Christmas Island.

It is maintained that the long-tailed cuckoo played a similar role in the discovery of New Zealand: "...Kupe had observed in his many voyages the flight of the *kokoperoa*, or long-tailed cuckoo, year after year, always coming from the south-west and wintering in the Central Pacific Islands. He and his compeers would know at once that this was a land-bird, and consequently that land must lie in the south-west" (Smith, 1921, p. 216).

Whether the paths taken by migrating birds really played any part as signposts in the Polynesian migration would seem, however, to be highly doubtful. At any rate the traditions do not support such a view. (Ed. *JPS*, 1907, p. 102.) In a discussion of Polynesian navigational methods it seems, therefore, that all speculations about the part played by migrating birds, and they are many in number, ought to be disregarded. On the other hand, it would appear to be beyond dispute that certain species of birds flying far out at sea provided the Polynesian navigator with evidence that there was land in the vicinity, and that by observing the routes they took morning and evening he was also able to find his way to land. It is uncertain whether such birds as a rule appeared out at sea at distances in excess of 50 miles from their own island.

Concerning this, P. Child, who has studied bird life in the Gilbert and Ellice Islands, writes: "The activities of noddies, terns and others often betray the presence of good shoals of bonito, trevally and other useful foodfish; their regular excursions from islets to fishing grounds, especially in the early morning and evening, provide a valuable guide for canoe captains as to the whereabouts of land. Probably much of the old Gilbertese navigation was based upon the regular flying routes of sea birds" (1960, p. 3).

ODOURS from fires, flowers, etc., ashore can be carried far out to sea by the wind and thus indicate that land is somewhere to windward. Gatty states that he has smelt the scent of new-mown hay 80 (!) miles off the coast of New Zealand (1958, p. 78). The same author introduces a somewhat unexpected Polynesian pilot — the pig. According to Gatty, the Polynesians often took pigs with them on their long ocean voyages, and pigs have a highly developed sense of smell. If the pigs smelt land while it was still well out of sight they became excited and “the Polynesians watched them closely” (*loc. cit.*)!

On one occasion Grimbles's Gilbertese navigator orientated himself when making landfall at Tarawa at night by the smell of the sea, not the smell from the land, since at that moment Tarawa lay to leeward. According to this Gilbertese the sea along the whole of Tarawa's south coast has a special smell. (1957, p. 57.)

5. Summary

The question concerning the permitted navigational error, posed in the introduction to this section, cannot be given a definite answer. Frankel considers that if the Polynesian canoe approached to within 120 miles from a low-lying island the navigator might just be able to reach his destination by observing cloud formations, the routes taken by birds, etc. If he approached to within 60 miles his chances of making a landfall were reasonably good, while from 30 miles they were very good. (1962, p. 40.)

A low-lying island can be sighted with the naked eye from a canoe about 11 miles off. Clouds above such an island can be seen from much greater distances, but as reliable reported values are lacking it is impossible to say what the maximum distance is. It is not quite clear how Frankel arrived at the upper limit, 120 miles, but it is conceivable that he sets this limit in accordance with reports that frigate birds sighted out at sea indicate land within about 100 miles. Against this Hilder states that he has often seen such birds more than 100 miles from land, though their direction of flight did not give any firm indication of the direction to land (1963 *b*, p. 189).

A more cautious assessment would seem to show that the Polynesian navigator would have to get within 40 to 50 miles of a low-lying island if, in favourable conditions, he was to stand a chance of making a successful landfall. This limit has been fixed with a view to the distance from their own island at which certain types of bird may normally be expected to appear. Where a mountainous island, such as Tahiti or Fatu Hiva, is concerned, it is possible of course to allow a greater margin of error in navigation and still retain a fair chance of a successful landfall.

The above is only applicable to making land during the hours of daylight. During long ocean voyages it must have been difficult, even impossible, for the Polynesian navigator to estimate his time of arrival at the destination, and the risk of sailing past a small target in the dark must, consequently, have been considerable.

We know, however, that the Polynesian navigators, like those in Micronesia, were, and to some extent still are, exceptionally skilful at orientating themselves by reference to the wind, the swell and clouds, etc., and that the correct interpretation of these phenomena is usually beyond a European. This knowledge, based on the accumulated experience of generations, would, however, seem to have been very localized, and to have mainly covered their own particular island and the neighbouring islands with which they were in more or less regular contact.

Landfall on island groups

It was very difficult for the Polynesian navigator, with his inexact methods of navigation, to reach a destination which consisted of an isolated island of limited size. The chances of making a successful landfall increased considerably if the destination was a mountainous area with a long coastline, or an island forming part of a large chain of islands, which could "catch" a canoe even if it had gone a long way off course. Consequently, if the navigator steered towards the middle of such a chain of islands he could expect to arrive at one or other of them, and then gradually make his way to his destination within the island group. (Hilder, 1963 *a*, p. 90.)

This navigational method has recently been discussed by Lewis (1964*b*, pp. 364 ff). If one draws a circle with a radius of 30 miles round each of the Polynesian Islands one finds that these circles overlap one another within large areas and form "island blocks". The islands within these never lie more than 60 miles apart and so a canoe which passes through the group is never more than 30 miles from land. In so doing Lewis has not taken account of the fact that certain "blocks" mainly consist of mountainous islands, which can be sighted at distances a good deal in excess of 30 miles. The following are examples of island blocks.

<i>Island block</i>	<i>Extent N-S</i>	<i>Extent E-W</i>
Tonga Islands	approx. 260 miles	approx 140 miles
Fiji Islands	370	230
Samoa Islands	110	260
Society Islands	160	310
Marquesas Islands	210	180
Cook Islands	120	200

Lewis is of opinion that the Polynesians were capable of making land on such "island blocks".

The island block theory may appear plausible, but there are a number of factors which make landfall of this type more difficult to accomplish in practice than in theory.

Hilder has observed that no account has been taken of the fact that it is possible to sail past islands in a group without seeing them because of darkness or reduced visibility. After several days or weeks at sea it is impossible for the Polynesian navigator to forecast the time of day or night at which a landfall will be made. It may, therefore, be necessary for him to heave-to by night so as to avoid sailing past an island or grounding on its reefs. While lying-to the canoe is subjected to a displacement of unknown dimensions and this will tend to increase the navigational error still further. There are, moreover, many island chains which, though long, are so narrow that it is possible to sail right through them at night without there being any chance of sighting any of the islands during the subsequent hours of daylight. However, Lewis is not unaware of these weaknesses in the island block theory, and he has himself described how, when sailing from Tahiti to Rarotonga, he passed through outer Cook one night, between Atiu and Takutea, without noticing either of these islands, despite the fact that they are only 10 miles apart (1966*b*, p. 89). Within many island groups the islands are so low-lying and the distance between them is so great that it is possible to sail through the group in broad daylight without sighting any of the islands. Many canoe voyages, which started as short trips between adjacent islands 30 miles apart, have turned into long drift voyages. (Hilder, 1963*a*, pp. 90—91; 1965, p. 249.)

If the island block theory is to be applied to regular contacts between distant island groups this presupposes that the Polynesians had a thorough knowledge of the geography of the island world. Sharp, who does not agree with this theory, wonders how Lewis imagines that the Polynesians were able to acquire such a knowledge, which would have to be comparable to our own (1965, p. 244). Obviously, the chances of making a successful landfall on an island group are much better if the group contains mountainous islands which can be sighted at a great distance. However, irrespective of the topographical nature of an island group, it would seem to be incontestable that it is easier to make a landfall on such a group than on an isolated island, and that navigation between island groups makes it possible to undertake longer ocean voyages than would otherwise be the case. This view is shared by Hilder, among others (1963*a*, p. 91).

If many canoes sail together the chances that one of them will sight

land will be increased if they spread out in a line at right angles to the course being steered. Erdland, and others, state that this procedure was adopted by the Micronesians, and that in this case the canoes were about 1 mile apart. During the night, or when visibility was reduced, contact was maintained between them by means of signals blown on conch horns. If the weather was bad and the canoes were in danger of losing contact with one another, they concentrated in a group and waited for an improvement in the weather. (Erdland, 1914, p. 61; cf. Firth, 1954, p. 92.) According to Smith the same form of search line was used by the Polynesians (1921, p. 186). This assertion is supported by Robert's reports from the Ellice Islands (1958, p. 412). The two last-named writers have not, however, verified their statements. Nonetheless it is plausible to assume that the Polynesians employed the same search method as the Micronesians. It is a simple method and one they might be expected to practise in order to improve their chances of making a successful landfall.

POLYNESIAN NAVIGATION. SUMMARY

The sailing season coincided with the trade-wind period, when the weather was at its most stable with often a clear sky and a steady wind. However, according to Pritchard, the trade wind could be extremely treacherous at times and lead to sudden spells of bad weather. It was also the Trade which gave rise to the many drift voyages from east to west, while the westerly winds, which usually blew harder than the trade wind, had not been observed to have caused corresponding drift voyages. (1866, p. 175.) In this connection it is worth mentioning Davenport's observations from the Santa Cruz Islands. Here the islanders know that during the trade-wind season the winds from the west and north, which are favourable for sailing to the islands of Tikopia and Anuta, situated to the south and east, are weak and temporary only, and that they are succeeded by easterly winds which can bring the voyagers back to their own islands. But the Trade is feared, too, because it can blow hard for weeks at a time and can result in the canoes disappearing for ever at sea or being carried away on long drift voyages. (1964, pp. 137—138.)

When the trade wind was blowing at its hardest, long voyages were avoided within the Carolines and the navigators instead sailed with the lighter winds which prevailed at the beginning and end of the trade-wind season. There is nothing to suggest, however, that this was also the case within Polynesia.

As a rule the Polynesians seem not to have sailed against the prevailing trade wind, and this can be explained by the fact that "the limitations in the construction of these canoes (i.e. the oceanic sailing canoes) due to material culture, must have sharply limited the length of time for which the canoe could withstand the strain of windward sailing" (Bechtol, 1963, pp. 100—101). If the destination lay to windward the voyages was postponed until the Trade had been temporarily superseded by winds from the western quadrant.

We cannot be sure that when voyaging eastwards the Polynesians did in fact sail with the westerly and northerly winds which occur more frequently outside the trade-wind season. These winds are more variable, the weather is poorer and is far from favourable for long ocean voyages.

Before a sea voyage, no matter how long or short, was commenced the Polynesian meteorologist carefully studied the weather and then announced the most auspicious time for the departure.

When embarking on shorter voyages, the start was timed for the afternoon so that landfall might be made as early as possible during the following morning. During the hours of daylight it was much easier to

discover the target from a distance, and if the destination had been overshoot the whole day could be spent searching for it. As no stars were visible at departure the course was sometimes set with the aid of constructed or natural landmarks. These made possible an exact compensation for the displacement of the canoe so that the true course could be steered as long as the marks were visible. The degree of accuracy achieved in maintaining course during the voyage was increased by the fact that the steering could be done by means of landmarks and stars during the greater part of the time at sea. This was an important point, since the canoes used for these shorter voyages were not of the more seaworthy ocean-going type and were not equipped for lengthy voyages.

In exceptional cases it appears that "beacons" in the shape of fires were arranged on the island to be visited. However, these could only have been used on islands which were near enough to be within optical signalling distance.

Landmarks do not seem to have been of much importance as far as long voyages were concerned. The slight increase in accuracy these might afford during the first hour or two of the voyages was of no real consequence in the context of the total sailing time. Long voyages probably began at dusk, the course being set by stars right from the start.

As soon as the stars became visible the navigator took up the course by steering on a succession of rising or setting stars with the same or nearly the same declination (horizon stars), which he knew from experience to be in line with the destination. About nine stars were needed during one night's sailing. The horizon stars could be taken either ahead or astern. As it may be difficult to find enough stars with the required magnitude, which rise (set) at the same point on the horizon, it is conceivable that the Polynesian navigator also steered by stars whose azimuth was only approximately the same as the true course. He would then have to compensate for this by steering to port or starboard of such stars.

Whenever possible the canoe was lined up between a rising and a setting star taken ahead and astern. It is probable, however, that this could be done only in exceptional cases, because it is rare to find suitable steering stars whose rising and setting points are exactly 180° apart.

The course being steered was checked in relation to true north-south obtained by observation of the Southern Cross when it was on the meridian. North of the equator the course could be checked throughout the night by reference to Polaris.

During the daytime the navigator steered the same course as was indicated by the horizon stars by observing the direction of the wind and the swell. A minor change in either one of these might, however, be very difficult to detect, and so the course was only approximately maintained.

Possibly the course could be corrected to some extent by observing the sun at sunrise and sunset and when it was on the meridian. As the steering stars are visible from about one hour after sunset to about one hour before sunrise, observations of the sun at rising and setting were of a little importance as regards maintaining the course, if one considers the many hours of daylight during which the steering would have to be performed without the help of any heavenly bodies, apart from the sun when it was on the meridian.

During a voyage the canoe is affected by several external factors which contribute to deflect it from the track. These are set and drift of the current, leeway and steering errors.

The displacement of the canoe due to ocean currents could not be determined out of sight of land, though it is possible that the navigator could compensate for this by experience when sailing to nearby islands over frequently used routes.

Leeway could probably be compensated for to some extent by an experienced navigator, while the magnitude of the steering error depended on the skill of the helmsman.

It is impossible to set forth in precise figures the accuracy of the Polynesian navigational methods, since there were at work so many different factors of which we know nothing for certain and which we can only evaluate very tentatively. The table below indicates the effect on the navigation of some potential errors. Against the distance made good, as the initial value, is shown the magnitude of the navigational error caused by steering errors, as well as displacement due to leeway and current. (It is emphasized that the values in the table are intended only to provide a general idea of the effect that steering errors, leeway and current could have on the navigation. They must not be taken as a measurement of the accuracy of Polynesian navigation.)

<i>Distance made good miles</i>	<i>Magnitude of navigational error (miles)</i>		
	<i>ce¹⁾ = 3°</i>	<i>ce¹⁾ = 5°</i>	<i>C²⁾</i>
90	4.5	7.5	15
180	9	15	30
360	18	30	60
600	30	50	100
900	45	75	150

¹⁾ ce = difference between course steered and true course as a result of steering error and incorrect compensation for leeway.

²⁾ C = canoe's displacement due to a current of 1 knot setting at right angles to the course. Canoe's speed 6 knots.

The course error depends on weather conditions, on the skill of the navigator in keeping on course by means of the stars, sun, wind and swell, and also on his skill in assessing leeway. On shorter voyages, which could be largely completed during one night's sailing with the use of steering stars, it is probable that the canoe could be kept on course more accurately (the course error being smaller) than was the case on long voyages. During the latter the navigator was forced to rely on the sun, wind and swell for several days when maintaining course, and this could give rise to considerable deviations from the intended track.

Opinions are divided concerning the accuracy with which a Polynesian migrant canoe could be steered. Estimates of error vary from as little as one or two degrees to as much as ten degrees (Hilder, 1963*b*, p. 188). Maintenance of course was made more difficult owing to the fact that the canoe could not, as a rule, be steered straight for a horizon star, but had to be steered a certain number of degrees off it in order to compensate for leeway, or because the star concerned lay to one side of the destination and was not directly above it.

The table makes it clear that even during a fairly short voyage of 90 miles, the navigational error, given a course error of 5° , will amount to 7.5 miles, i.e. about the distance from which an atoll can be sighted from the deck of a canoe.

The displacement of the canoe owing to ocean currents also contributed to the uncertainty in navigation. As the set and drift of ocean currents can be extremely variable, it is hazardous to offer any estimate of their influence on the accuracy of the navigation. The effect of the current can vary from time to time along the same route, and this can mean that one canoe will make a successful landfall, while another canoe sailing at a different time may not.

The figures (for 1 knot) given in the table merely indicate the possible effect of the current. It is unlikely that during a long voyage the current would set unceasingly with a constant speed at right angles to the course.

The canoe's speed is given as 6 knots. This is not definite because we do not possess any facts concerning the average speed a heavily laden migrant canoe could maintain. Hilder is of opinion that such a canoe would hardly be able to attain an average speed in excess of 4 knots, while Frankel and others hold the view that a speed of about 10 knots ought to be allowed for (Hilder, 1963*b*, p. 191). No universally acceptable answer can be given to this question because the speed is, of course, dependent on the type of canoe used for the voyage, the length of the voyage, weather conditions, etc.

For speeds in excess of 6 knots the displacement as a result of current is less than that given in the table, while for lower speeds it is greater.

Navigation by horizon stars during the night, and by the sun and the direction of the wind and the swell during the day, amounts in principle to what is called dead reckoning, an assessment of the canoe's position based on an estimate of the course and distance made good. The method did not permit any determination of latitude and longitude. As we know that the Polynesian navigator had no possibility of determining longitude the theory was put forward that he sailed by the latitude method (latitude sailing), which requires only a determination of latitude. It was in this way that the theorizer helped the Polynesian navigator to solve his longitude problem. However, as has been previously shown, there is a complete absence of evidence that the Polynesians used this method or even that they knew how to determine latitude. It is known that the Polynesians closely observed the heavenly bodies, and for this reason it is probably true that they were well aware that the firmament changed its appearance with a change in latitude. But this does not justify drawing the conclusion that this knowledge also meant that they were able to determine the latitude through measuring the altitude of a star. It is possible that they could estimate latitude roughly, but we do not know that this was so.

Polynesian navigational methods were marred by many shortcomings, which means that the navigational error could be of such dimensions even over short distances (of the order of 100 miles) that landfall on a target of limited extent might seem doubtful. Making land successfully does not demand precise navigation, but it does require the canoe to be brought so close to its destination that the latter can be sighted or can be found by observing natural indications that there is land in the vicinity, i.e. cloud formations, routes being taken by birds, etc. The permissible navigational error, consequently, largely depended on the elevation of the destination and also on its extent. If the destination was an isolated low-lying island the voyage could be risky even if the distance to be sailed was no more than 70—80 miles (Firth, 1954, pp. 92—94). Where the target was a mountainous island the problem was easier, and even if it was isolated it was possible to maintain regular contacts over quite considerable distances. Thus the Tongans often sailed to Rotuma, probably via Fiji, a total sailing distance of about 650 miles, of which a maximum of about 270 miles was over the open sea. The navigational error increased with the distance sailed, but to some extent this could be compensated for if the voyage took place between island groups which could "catch" the canoe. The danger of passing through such a group without sighting any of the islands was always present, however, if the conditions were not favourable.

The Polynesian navigational methods cannot be regarded as allowing

the maintenance of regular contacts between islands or island groups so far apart that the sailing time out of sight of land amounts to many days or weeks. In such cases it seems impossible for the navigator to determine the position of the islands (or groups) in relation to each other, since he did not possess the ability to determine the longitudinal error during the voyage, and, in all probability, was unable to determine the latitude with the required accuracy. Suppose that the canoe has reached a distant, previously unknown island. What course is the navigator to steer in order to return to the point of departure? The horizon stars which had, for example, been taken ahead on the outward voyage will have to be taken astern on the homeward leg. But how great was the displacement of the canoe during the outward passage and how is the navigator to compensate for this when he is homeward bound? It is not possible to solve this problem with the Polynesian navigational methods and so the return voyage will be a very risky enterprise. Navigation between island groups can improve the prospects of a successful landfall, but this presupposes that the navigator possesses a detailed knowledge of the geography of the island world. It is doubtful if he could acquire such knowledge without knowing how to fix his position accurately. (Cf. Sharp, 1963, pp. 33—53.)

Some long-distance voyages within Polynesia

1. Introduction

It has been established that at the time Europeans penetrated into the Pacific Ocean the Polynesians probably maintained regular contact, involving ocean voyages of more than 100 miles between the following islands or island groups: the Society Islands—the Tuamotu Archipelago (about 170—230 miles), Tonga—Samoa (about 130—360 miles), Tonga—Rotuma (about 300 miles)—Ellice Islands (about 200 miles), Tonga—Fiji (about 220 miles), Rarotonga—Atiu (about 115 miles). (Sharp, 1963, p. 32.) Thus the longest distance sailed across open seas was some 300—360 miles. With a favourable wind the distances mentioned could have been covered in about 48 hours and less. If the destination lay in the direction from which the trade wind blew, as in the case of the Fiji—Tonga route, the voyage was postponed until the trade wind was temporarily superseded by a westerly wind. According to Denning voyages within and between these contact areas meant that distances of close on 1000 miles were sailed, though the longest distance covered while out of sight of land would, on average, be no more than 150—230 miles (1963, pp. 125—126).

Can it be that the Polynesians never maintained regular contacts between islands or island groups involving distances greater than those reported here?

To provide a basis for a discussion of this question it is necessary first of all to give a survey of the migrations within Polynesia as they appear in the light of recent research. In this way the initial data required for a nautical analysis will be obtained: point of departure, destination and distance. On the basis of these three items an investigation can thereafter be made of the probability that post-colonization contacts were maintained along migration routes where the distances exceeded 300—400 miles.

The survey is based on an article entitled “East Polynesian Relationships”, by Kenneth P. Emory (1963, pp. 78—100), which in turn was based mainly on glotto-chronological and archaeological investigations. By thus using Emory’s discoveries the great advantage will be gained that Polynesian voyaging traditions, which give rise to extremely subjective evaluations and interpretations, need not be consulted. It is true that Emory’s conclusions have been subjected to a certain amount of criticism, most recently from Roger Green (1966, pp. 6—38), but this criticism is con-

cerned in the main not with the extent of the migration routes, but with the absolute dating of the migration, a matter which is of no importance for the discussion which follows.

Emory gives two alternative migration routes:

(a) The Society Islands as the central area for the migrations within eastern Polynesia.

Tonga—Samoa (c. 1500 B.C.) to Tahiti	c. 700 B.C.
Tahiti to the Marquesas Islands	100
The Marquesas Islands to Easter Island	500 A.D.
Tahiti to Hawaii	500
Tahiti to New Zealand (via the Cook Islands)	1000
The Marquesas Islands to Mangareva	1000
Tahiti to Hawaii	1200

It is possible, however, that the Marquesas Islands were colonized directly from Tonga before the seafarers from Tahiti reached the Marquesas Islands.

(b) The Marquesas Islands as the central area for the migrations within eastern Polynesia.

Tonga—Samoa (c. 1500 B.C.) to the Marquesas Islands	c. 700 B.C.
The Marquesas Islands to Tahiti	100
The Marquesas Islands to Easter Island	300 A.D.
The Marquesas Islands to Hawaii	750
The Marquesas Islands to Mangareva	900
Tahiti to New Zealand (via the Cook Islands)	900
Tahiti to Hawaii	1200

It is possible that Hawaii was colonized not from the Marquesas Islands alone or from Tahiti alone, but from both areas.

Suggs, on the other hand, holds the view that there is evidence that Hawaii was not colonized from the Marquesas Islands (1965, pp. 209—210).

The tables above afford a schematic outline of the longest sea voyages the Polynesians had to accomplish during the colonization phase. Were these one-way voyages only, or were there repeated contacts between the island groups by means of intentionally planned two-way voyages? If the latter, then it presupposes that the first colonizers of new land were able to perform their voyage of discovery possessing complete navigational control, thus making a return passage to the home islands possible. Suggs

is among those who consider that this was the case as regards voyages between Tahiti and Hawaii, and also between Tahiti (Rarotonga) and New Zealand, while Sharp and others hold the opposite view. As these two voyages have been singled out for debate, owing to their unusual length, an attempt is made below to supply a brief analysis of them.

2. *Tahiti/Marquesas Islands—Hawaii*

Distances: Tahiti—Hawaii	approx. 2200 miles
Nuku Hiva—Hawaii	1900
Tahiti—Nukuhiva	780

(1) Meteorology

Tahiti—Hawaii: The trade wind will allow a canoe to sail with the wind abeam or slightly before the beam. A return voyage would likewise have favourable winds. The ocean currents will set the canoe westwards. Heyen judges this to be the easiest of the Polynesian long-distance voyages to undertake (1963, p. 73).

Nuku Hiva—Hawaii: By and large this route is also favoured by advantageous winds. However, on a return voyage by the same route the canoe would have to sail fairly close-hauled and this would impose considerable strains on the vessel. The equatorial currents would set the canoe westwards, while the counter-equatorial current would set it eastwards. On the return voyage the ocean currents would be somewhat adverse, thus involving more sailing time than the outward passage.

(2) Traditions and theories about voyages

(a) According to the Hawaiian historian Kamakau, tradition gives the following directions for the voyage from Hawaii to Tahiti:

“If you sail for Kahiki (Tahiti Island) you will discover new constellations and strange stars over the deep ocean. When you arrive at the Piko-o-wakea (Equator) you will lose sight of Hoku-paa (the North Star), and Newe will be the southern guiding-star, and the constellation of Humu will stand as a guide above you” (Best. 1923*a*, p. 37).

It is obvious that the form in which the tradition here reproduces the sailing directions for the voyage from Hawaii to Tahiti they will not have been of much value to the navigator. They may possibly be interpreted as fragments of long forgotten, more detailed directions for this voyage, and thus constitute an indication that intentional voyages

were accomplished between these two island groups. As has been pointed out previously, the reliability of Kamakau's traditions must, however, be seriously questioned, and so caution requires us to refrain from attaching too much importance to the quotation above. Apart from this, there is no other source from which verification can be obtained.

(b) In the year 1817 a chant, "The Birth of New Lands", was noted down on Raiatea. In the chant is described how new land is born from the sea when the morning star touches the waves. Some island groups are thought to have been identified, among others, the Society Islands, the Marquesas Islands, the Tuamotu Islands and Hawaii (burning Aihi), while others are completely unknown. (Henry, 1928, pp. 399—402.) The equating of Hawaii with Aihi, however, is very uncertain.

Makemson is of opinion that this song gives sailing directions for the voyage between Raiatea and Hawaii and by reference to the heavenly bodies mentioned she has made a reconstruction of the course to be steered (1941, p. 20). According to Makemson the song makes it clear that the voyage was not made direct from Raiatea to Hawaii, but via the Marquesas Islands. The reason for this detour, again according to Makemson, was that on a direct voyage the displacement caused by current and wind would set the canoe far to the west of the longitude of Hawaii, in addition to which the trade winds would be more favourable when sailing via the Marquesas Islands. From these a north-westerly course was steered until, after having passed through the Doldrums, the canoe reached the north-east trade wind, which allowed good progress to Hawaii. So as to be sure of arriving at the destination a course was steered somewhat to the east of it, and on reaching the latitude of Hawaii, which was determined with the help of Aldebaran, a star standing a degree or two south of Hawaii's zenith, the course was set due west towards Hawaii, which could be sighted from a considerable distance owing to the glow from its volcanoes. Makemson is of opinion that the voyage was accomplished during the summer months, when numerous cyclones are formed in the Doldrums. These cyclones generally move north-west and so are suitable for bringing a canoe to the vicinity of Hawaii.

Without analysing Makemson's reconstruction in detail the following comments may be made:

The material on which the conclusions and the reconstruction are based is meagre and difficult to interpret. There is a good deal of uncertainty concerning many of the names of islands and heavenly bodies mentioned in the chant. Thus Makemson bases her identification of Aldebaran mainly on the fact that this star is near the zenith of Hawaii. Henry, on the other hand, has identified the star as Orion (1907, p. 102).

It has already been shown that it is improbable that the Polynesians were able to determine the latitude with satisfactory precision by observing a zenith star or that they could combine such a determination with latitude sailing.

It would appear most improbable that the Polynesians planned their voyages to a distant island so as to obtain the help of cyclones from the south—east. In such circumstances the prospects of navigation by the heavenly bodies were greatly reduced, besides which there was a grave risk of the canoe being wrecked. What we know of the Polynesians' careful planning of long-distance voyages with regard to weather leads us to quite different conclusions.

Sailing along this route calls for an intimate knowledge of the prevailing winds and currents and this can only be gained through experience, that is to say, after repeated voyages along the same route.

(c) As early as 1927 the American Admiral H. Rodman advanced theories similar to those of Makemson concerning the voyages made by the Polynesians from Tahiti to Hawaii via the Marquesas Islands. According to Rodman the return voyage to Tahiti, on the other hand, was a direct one owing to the fact that this route was more favourable as far as wind and current were concerned. The outward voyage was to a position well to the east (to the windward) of Hawaii, which was thereafter reached by latitude sailing. (1927, pp. 869—872; cf. Fig. 5.)

The difference between these two theories is found in the fact that Makemson considered that the latitude was determined by means of a zenith star (Aldebaran), while Rodman maintained that it was determined by measuring the altitude of Polaris with the aid of the "sacred calabash". Rodman's theory calls for the following comments:

The instrument alleged to have been used, the "sacred calabash", was fictional, as has previously been mentioned.

One thousand years ago Polaris stood about 5° from the pole, and was, in other words, circumpolar. It could not be relied on to indicate the latitude exactly.

There is nothing to suggest that latitude sailing was a navigational method adopted by the Polynesians.

Voyaging along this route requires an intimate knowledge of prevailing winds and currents (cf. above).

(3) Conclusions

The above-mentioned theories concerning voyages to Hawaii assert that these were two-way voyages. What proof is there of contacts between the Society Islands, the Marquesas Islands and Hawaii? Provisional

answers to this question have come mainly as a result of archaeological and glotto-chronological investigations (Emory).

(a) Hawaii was colonized, probably some time between A.D. 500 and A.D. 800, by seafarers from the Society Islands/the Marquesas Islands or from both these areas.

(b) Seafarers from Tahiti made renewed contact with Hawaii about A.D. 1200.

(c) It is very doubtful whether Tahiti and the Marquesas Islands were in contact with each other after the initial migration to Polynesia. On the other hand, contact between seafarers from both these areas might have occurred within the Tuamotu Archipelago (Suggs, 1965, p. 214). At all events an influence from late Tahitian culture can be traced in the Marquesas Islands (Emory, 1963, p. 91).

(d) One of the ten pillars, which according to Tahitian cosmology, supported the dome of heaven, was named after Polaris, which is visible only north of the equator, that is to say, only in the Hawaiian part of the Polynesian island world. There is no way of deciding whether or not the name of this star reached Tahiti only after the European contact had been made (cf. p. 45).

The archaeological investigations within Polynesia are still in their initial stages and as yet no firm conclusions concerning the migrations within the island world can be drawn from them. At the present time, though, it would seem as if the contacts between the Society Islands, the Marquesas Islands and Hawaii were sporadic in the extreme.

The Makemson-Rodman theory presupposes that the sea voyages from Tahiti to Hawaii were accomplished via the Marquesas Islands. If these voyages are not to be regarded as one-way voyages, the Tahitian culture ought to have left definite traces in the Marquesas Islands during the repeated contacts that are assumed to have been made. This, however, is not the case. It would seem that only a certain influence from late Tahitian culture can be demonstrated. Consequently, it appears unlikely that any sea voyages the Tahitians may have made to Hawaii went via the Marquesas Islands, and for this reason alone the theories of Makemson and Rodman would seem to be irrelevant to this discussion.

Immigrants from Tahiti (the Marquesas Islands) reached Hawaii, probably as early as about A.D. 500. Archaeological finds and the presence of influence from late Tahitian culture make it probable that voyagers

from Tahiti reached Hawaii again about A.D. 1200. So far it has not been possible to find any evidence of contacts in the reverse direction. There is, then, nothing to support the view that there existed anything that might be interpreted as more or less regular communications between these two areas.

On the basis of available material the Polynesian sea voyages to Hawaii are more likely to have been one-way only. That is to say, the island group was colonized from Tahiti and/or the Marquesas Islands at the same time as it was discovered by fleets which, in all probability, were well equipped. It is not likely that these seafarers returned to their home islands to report on the newly discovered land. This conclusion is supported by the fact that between 500 and 700 years probably elapsed before Tahitian voyagers again reached Hawaii, while no renewed contact between the Marquesas Islands and Hawaii seems to have occurred. It seems likely that the second Tahitian contact with Hawaii was the result of a rediscovery and was not a new colonization enterprise based on sailing directions preserved in old traditions.

The migrations thus appear as one-way voyages, and this is in keeping with what we know about the Polynesian methods of navigation. The fact is that these methods did not permit them to navigate with a satisfactory degree of accuracy over distances of the size we are concerned with here, mainly because they did not allow any determination of longitude and probably none of latitude, either.

From the nautical point of view the prevailing winds were relatively favourable for voyages in both directions, and the various archipelagoes formed island blocks extending east and west (Hawaii, the Society Islands), which in theory could to some extent compensate for the error in longitude. However, it has not been possible to point to any facts which suggest that a contact was maintained between eastern Polynesia and Hawaii, while the archaeological and nautical objections to such a contact are considerable.

The conclusions which can at present be drawn with the help of glotto-chronological and archaeological material should, however, be regarded as provisional only, and the reservation must be made that future research into the migration problem may be accompanied by discoveries which will necessitate a revision of the picture outlined here of the relations between eastern Polynesia and Hawaii.

3. (Tahiti)—Rarotonga—New Zealand

Distances: Tahiti—Rarotonga	approx. 525 miles
Rarotonga—New Zealand	1500

(1) Meteorology

The trade winds prevail only within the most easterly part of the route. Further to the west the winds are variable, particularly in the coastal areas of New Zealand. Between lats. 30° S and 35° S winds from between east-north-east and south are fairly frequent during the period January—April, while winds from the western quadrant prevail during the rest of the year. During the months January to April there is no correspondingly high frequency of easterly winds between lat. 35° S and lat. 45° S; westerly winds prevail during the other months of the year. South of lat. 45° S west winds become predominant with increasing latitude. The frequency of gales is low, but even so it is higher than in other parts of Polynesia. The most severe gales are usually those from the west.

Between the southern limits of the south equatorial current, at about 20° S, and the northern limits of the eastward-flowing “west wind drift”, at about 45° S, there is a region with variable currents.

Consequently, the meteorological conditions are unfavourable for sailing from Rarotonga to New Zealand.

(2) Traditions and theories about voyages

The traditions concerning sea voyages to and from New Zealand are especially comprehensive. The discovery of New Zealand is attributed to the Tahitian seafarer, Kupe, and on the basis of genealogical calculations has been dated to some time in the 10th century A.D. Kupe returned to his native country, gave an account of his discovery and supplied sailing directions for the voyage. Guided by Kupe's directions Polynesian colonizers sailed to New Zealand. The leading names are Toi in the 12th century and “the Fleet” in the 14th century. The following different versions of the sailing directions to New Zealand can be found in the traditions:

- (a) “Keep the sun, moon or Venus just to the right of the bow of the vessel and steer nearly south-west” (Best, 1922*a*, p. 29).
- (b) “Let the course be to the right hand of the setting sun, moon or Venus in the month of February” (Smith, 1921, p. 216).
- (c) “Carefully keep the prow of the vessel laid on Venus during the night; during daytime follow behind Tama-nui-te-ra (the sun)” (Best, 1922*a*, p. 28).
- (d) “Tradition states that the stars relied on during the voyage hither of ‘Takitumu’ were Atutahi (Canopus), Tautoru (Orion's Belt), Puanga (Rigel), Karewa, Takurua (Sirius), Tawera (Venus as morning star), Meremere (Venus as evening star), Matariki (Pleiades), Tama-rereti (Tail of Scorpion?), Te Ikaroa (the Galaxy)” (Best, 1922*a*, p. 28).

The North Island of New Zealand extends about 450 miles in a north-south direction and from Rarotonga affords a target covering about 15° . Providing that the navigator knows the course and that the wind is favourable a canoe could cover the distance in about two weeks. As the target is large precise navigation is not necessary.

According to the first two versions the canoe is to be steered somewhat to the left or somewhat to the right of the setting sun. The rapid change in the declination of the moon makes it unsuitable as a "steering star", and so the moon should be ignored in this connection. February is given as the time for the voyage, but other versions give the end of November or the beginning of December.

The course from Rarotonga to the Bay of Plenty, where the traditions say most of the canoes made the land, is about 230° . At about the time of the winter solstice the bearing of the setting sun is about 245° at the latitude of Rarotonga. By holding a course some 15° to the left of the setting sun (version [a]) a canoe would, consequently, be able to reach the North Island if winds and currents were favourable (cf. Makemson, 1941, pp. 27—30).

In the third version the sailing directions, according to what appears from other traditions, refers to the rising sun. This means that the canoe was to steer an easterly course from Rarotonga, and so the tradition cannot refer to the voyage from Rarotonga to New Zealand. Venus is never more than 30° from the sun and thus cannot act as a guiding star "during the night".

In the fourth version the names are given of stars spread all over the firmament. The directions are quite meaningless. A star with a declination of about 37° S is necessary as a guiding star. Of the stars mentioned, only certain stars in Scorpius fulfil this requirement.

Hilder has drawn attention to the fact that the course from Rarotonga to New Zealand is almost identical with the course that was indicated by landmarks on Atiu for voyages to Rarotonga. However, he considers it most improbable that seafarers from Atiu, who failed to find Rarotonga, a two day's run, would continue to sail for several weeks on the same course and finally end up in New Zealand. (1963a, p. 97.)

(3) Conclusions

The many traditions preserved about sea voyages to and from New Zealand have been accepted by the traditionalists as proof that such voyages took place in pre-European times, and were well-planned expeditions which were accomplished in accordance with navigational directions based on experience.

To what extent can these hypotheses be supported by the archaeological and glotto-chronological discoveries?

New Zealand was colonized about A.D. 900, from eastern Polynesia, probably Tahiti (possibly also the Marquesas Islands). Glotto-chronological investigations support the view that these emigrants did not make straight for New Zealand, but that they first reached the Cook Islands (Rarotonga) and remained there for an unknown period before New Zealand was finally discovered and colonized (Emory, 1963, p. 98). Here science seems to confirm what the tradition has to say about the route the Polynesian took from Tahiti to New Zealand.

The tradition relates that after Kupe discovered New Zealand the Polynesians made their way there in several waves, the last one being in the 14th century, when "the Fleet" reached North Island. Archaeological excavations made in recent years in the Society Islands (Maupiti), among other places, have yielded interesting results which throw a new light on these traditions:

"It would seem that, if the 'fleet migration' of New Zealand's traditional history, which supposes New Zealand to have been already occupied by previous settlers, actually took place in about the beginning of the 14th century as has been generally believed, it would have carried the same influences as those which reached Hawaii at about this time. There seems to be no certain evidence as yet in New Zealand archaeology of an incoming of culture from East Polynesia other than that reflected in the culture of the Moa-hunters. Therefore, those who came by the traditional 'fleet' may have been, after all, the original settlers of New Zealand, and the shortness of the genealogies misleading as to the length of time which lapsed since their arrival." (Emory & Sinoto, 1964, p. 159.)

Roger Green has dealt with the migrations within Polynesia from the linguistic point of view. In so doing he has also drawn certain conclusions concerning the emigrations to New Zealand, which are important in any discussion of the reliability of the traditions:

"For instance, one cannot help but be impressed with the fact that there are two main groupings of tribes in New Zealand, those with several different Toi and those with Kupe, as origin ancestors, and these groups are in complementary distribution within New Zealand; neither origin ancestor ever appearing on a valid genealogy of the other group" (1966, p. 31).

"What I suggest is that decisive settlements early in New Zealand's prehistory, from both the Tahitian and Marquesan areas, could have given rise in New Zealand to two (or more) New Zealand East Polynesian subcultural traditions, and that together after long contact in favourable areas of the North Island of New Zealand, these laid the basis for the

later development of Maori culture without any recourse to the concept of the fleet. In fact, two origins could be the basis for the various canoe traditions which have since been elaborated and are now wrongly interpreted by the last few generations of traditional scholars." (1966, p. 33.)

(The possible migration route from the Marquesas Islands to New Zealand is not mentioned by Emory.)

Thus the traditions about voyages to and from New Zealand are not confirmed by archaeological and linguistic investigations; on the contrary, they are refuted. Sharp has previously criticized very severely the traditionalists' historiography and has maintained that the traditions do not reflect the true historical course of events. He basis his view primarily on his own analysis of the traditions, but he also refers to earlier critical statements. Wilhelm Colenso, one of the few Europeans who lived among old-time Maoris, had this to say (in 1868) about the voyaging traditions which concern New Zealand: "In all this mythical rhapsody there is scarcely a grain of truth; and yet some educated Europeans have wholly believed it. The New Zealanders themselves never did so." (Sharp, 1963, p. 79.) Henry Stowell, who was taught by Maori priests in the 1870s, was of opinion that "there was no migration to New Zealand in a fleet and that the tribal leaders who were reputed to have arrived in the fleet were New Zealand-born ancestors round whom fables had been woven" (Sharp, 1963, p. 119).

Regular contacts between New Zealand and East Polynesia did not occur. This conclusion confirms what we know about the navigational methods of the Polynesians: they were not sufficiently accurate to permit of sea voyages for long distances out of sight of land. The meteorological conditions along the route New Zealand—Rarotonga were, moreover, unfavourable, with great variations in winds and currents. From a nautical point of view alone two experienced navigators, Brett Hilder and G. H. Heyen, have analysed the Polynesians' chances of making such a voyage. Working independently, they have both arrived at similar conclusions: "... it would appear that direct voyages from Tahiti to New Zealand, although theoretically possible, would be beyond the capabilities of the old native navigators" (Heyen, 1963, p. 74); "Intentional voyages of this range require knowledge both of navigation and geography far beyond that found in Polynesia in Cook's time or since, and I firmly conclude that the voyages to New Zealand were accidental" (Hilder, 1963a, p. 97).

4. East Polynesia—Easter Island—South America

Nobody has yet seriously maintained that regular contacts were maintained over these routes, and so strictly speaking this section falls outside

the scope of this essay. However, as indubitably the Polynesians did reach Easter Island and as there has been much speculation about whether they were also able to reach the coast of South America, it may be of some interest to examine briefly the nautical prerequisites for such voyages. They cannot be dealt with from any other point of view, since neither tradition nor factual evidence provides any clues as to how the voyages were carried out or, in the case of the East Polynesia to South America route, might have been carried out.

(1) Meteorology

Within this particular area of the ocean the trade wind prevails for most of the year and is most stable off the coast of South America. The southern limit of the trade wind varies somewhat according to the time of year, but in general lies a little to the north of the latitude of Easter Island. Between the trade-wind zone and the northern limit of the westerlies to the south there is a region where the winds are light and variable. The trade-wind zone in the southern hemisphere stretches somewhat north of the equator as far as the Doldrums, within which flows the counter equatorial current. Within the trade-wind zone the westward-setting south equatorial current is found, its boundaries coinciding in the main with those of this zone. Off the coast of South America there are strong northerly and north-westerly currents which become part of the south equatorial current.

(2) Easter Island—South America

(a) Easter Island was colonized probably from the Marquesas Islands and possibly around A.D. 500, which, surprisingly enough, is much earlier than the colonization of Mangareva in the south-east of the Tuamotu Archipelago, an island lying about 1400 miles west-north-west of Easter Islands and, for geographical as well as meteorological reasons, obviously much easier to reach. Easter Island is the Polynesian island which lies nearest to the South American continent. Was it possible that the Polynesians were able to reach that continent from or via Easter Island? Hornell is of opinion that it would not have involved insuperable difficulties for them to have steered an easterly or north-easterly course as far as the Peru Current and, with its help, make land on the coast of northern Peru or Ecuador. A return voyage by the same route can be dismissed as an impossible enterprise owing to unfavourable currents and winds. The voyagers could have returned via the Marquesas Islands

only by steering north-west from Peru and taking advantage of the Peru Current, the south equatorial current and the trade wind (cf. Heyerdahl's Kon-Tiki route). This would demand geographical and meteorological knowledge on a scale we cannot suppose the Polynesians to have possessed. Hornell's view is that it is well within the bounds of possibility for the Polynesians to have reached the coast of South America from Easter Island, but that it is unlikely in the extreme that they ever succeeded in making the return voyage (1945, p. 188).

Hornell assumes that the voyagers either set out from Easter Island or that this island served as a port of call for seafarers coming from other island groups within East Polynesia. In the latter case it is presumed that they knew the position of Easter Island and that they had planned beforehand to use it as a rallying point. It is not very likely that this was the case since the Polynesian navigational methods almost certainly did not allow them to maintain contact with so isolated a place as Easter Island. If the Polynesians reached it on frequent occasions then such events can only be described as rediscoveries, and cannot be regarded as the result of planned navigation towards a known destination.

It must, however, be regarded as very doubtful if it really was possible for the Polynesians to reach South America from Easter Island (or from the Tuamotu Archipelago) via the route assumed by Hornell. The trade-wind and the currents are not advantageous; in fact they are mostly the very opposite and are certainly by no means "extremely favourable" as Hornell claims.

(b) Paul Adam, the French anthropologist, considered it unlikely that it lay within the capability of the Polynesians to accomplish voyages to South America in the way Hornell has suggested. But because he himself wanted to see them there he has presented his own theory of how they went about it, "*une nouvelle hypothèse*" (1955, pp. 21—31).

Starting from Easter Island the Polynesians, Adam suggests, made their way southwards through the trade winds to the prevailing westerlies and the eastbound, later northbound currents, which carried them up to the coast of Peru. The route is given in Fig. 6 and on the whole coincides with that followed by 19th- and 20th-century sailing ships when voyaging from San Francisco to Callao.

A profound knowledge of the winds and currents of the south Pacific Ocean is demanded of the navigator who follows this route. It is completely unrealistic to assume that the Polynesians had been able to secure this knowledge, which can only be gained through a meteorological and hydrographical investigation of vast areas of the ocean. The complicated route, a southern initial course and a northern final course, also pre-

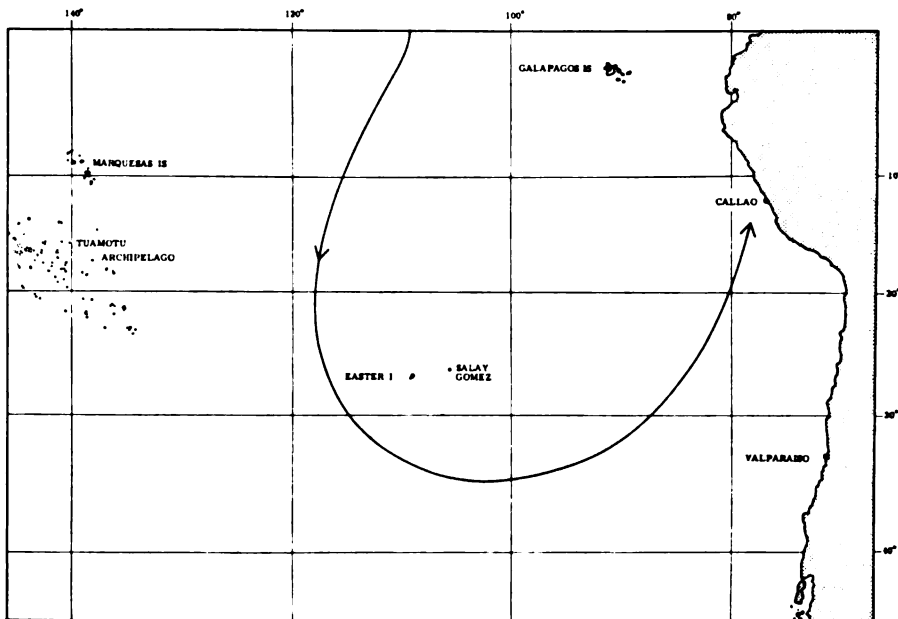


Fig. 6. The sailing-ship route San Francisco—Callao (after *Ocean Passages for the World*, 1950).

supposes that the existence and approximate location of South America were already known.

(3) The Marquesas Islands—South America

(a) Due east to the coast of Peru or Ecuador. The route involves sailing against the trade wind and the south equatorial current and, further east, against the Peru current. It can therefore be regarded as quite improbable that the Polynesians were able to take this route.

(b) Sailing north about 700 miles to the Doldrums between the trade-wind zones of the northern and southern hemispheres, then east towards the Bay of Panama taking advantage of the counter-equatorial current. Adam has come to the conclusion that this route cannot have been used. The east-setting current is weak, and calms alternate with winds of varying strength and direction, thus making this area among the least attractive for sailing ships. Even if canoe voyagers had the capacity to spend several months in the Doldrums, Adam considers that any progress eastwards with calms alternating with squalls would be virtually out of the question. (1955, p. 23.) One can but agree with this view.

Theories and discussions about different routes from East Polynesia to South America cannot lead to an answer to the question whether the Polynesian seafarers really did reach South America. All they can do is clarify the nautical conditions and afford a basis for a more or less subjective assessment of the probability or improbability of this having occurred. Any view expressed can only be vaguely formulated. From the nautical point of view the possibility that the Polynesians did reach South America cannot be altogether excluded, but, on the other hand, it is improbable that this was the result of carefully-planned, navigated voyages. In addition, it is not likely that those who may have reached that continent possessed sufficient geographical and meteorological knowledge to enable them to accomplish a return voyage.

5. Summary

(a) It has been established that the Polynesians, in post-European times, maintained two-way contacts over distances in excess of 100 miles between the following islands and island groups: the Society Islands—Tuamotu Islands; Tonga—Fiji; Tonga—Samoa; Tonga—Samoa—Fiji—Rotuma—the Ellice Islands; Rarotonga—Atiu.

(b) Opinions are divided concerning the possible existence of further contact areas in pre-European times. From the nautical viewpoint it is not impossible that the Polynesians were able to maintain contact between island groups other than those named above. In this event the distances involved need not, therefore, have been greater than those between the contact areas specified. However, there is as yet no proof of this.

(c) In the discussion concerning the sea voyages within Polynesia one of the opinions expressed is that the voyages made by the Polynesians in the 18th century cannot permit us to draw any conclusions concerning the extent of their voyages in pre-European times, and that everything suggests that their great era of voyaging ended in the 15th century, that is, long before the Europeans penetrated into the Pacific Ocean. It is considered that the traditions contain evidence in support of this view, and it is maintained that the explanation for the discontinuance of the long voyages, and for the fact that they were no longer undertaken in historical times, is to be found in a phenomenon of degeneration, for which there is no explanation.

The question which has perhaps attracted the greatest interest is that dealing with the sea voyages to remote islands and island groups,

that is to say, voyages which entail covering distances of 1000 miles and more. It has been asserted that the Polynesians reached such destinations as Hawaii and New Zealand not once but many times, guided by specific sailing directions. Support for this view has mainly been sought in the traditions.

What we know of the navigational methods of the Polynesians does not, however, serve to confirm the soundness of these theories. At the present time, the results of archaeological and other investigations also seem to disprove what the traditions relate in this respect. It is likely that after its colonization New Zealand did not have any renewed contact with the rest of Polynesia and also that after its initial discovery Hawaii was not visited again by voyagers until between 500 and 700 years later. There is also an absence of proof that more regular contacts took place between neighbouring island groups, such as the Society Islands and the Marquesas Islands, in spite of the fact that such contacts, via the Tuamotu Islands, are not impossible.

As far as one can judge, the Polynesian long voyages always were very rare occurrences. Up to the present nothing has emerged which supports the hypothesis of the degeneration of voyaging after the 15th century, or the belief that at one period the Polynesians were more daring seafarers and better navigators than they were at the time when the Europeans first made contact. A degeneration indisputably occurred, but this was probably largely a direct result of European influence on the Polynesian culture.

(d) The Polynesian voyaging traditions are numerous, but they have never been the object of any rigorous critical analysis of the sources. For this reason the value of the traditions in historical reconstructions is very doubtful. Thus, Fornander had pointed out that the tradition about Hawaii-loa, the discoverer of Hawaii, probably included accounts of many different seafarers from different regions and generations, but that in time Hawaii-loa came to be a central heroic figure who was credited with all these voyages of discovery and adventure (1878, p. 137). Similarly, Sharp seeks to show that the accounts of the Maoris' Kupe and the Tupa of the Marquesas Islands and Mangareva are only variations of the same west-Polynesian tradition, adapted to satisfy local needs. One indication of this, among others, may be Kupe's directions for the voyage from Rarotonga to New Zealand: "Steer towards the rising sun", which of course involves setting a course in the opposite direction. It may be that this is a reminiscence of the Polynesian migrations from west to east.

Suggs has also assumed a very critical attitude towards the way in

which the traditions have been collected and made use of for reconstructing Polynesian prehistory. He recommends a thorough evaluation and criticism of the material and is of opinion that it would be possible in this way to exclude from consideration a number of currently accepted traditions, thus imposing a severe check on the proliferation of theories about Polynesian sea voyages.

(e) It is probable that in the main the two-way voyages of the Polynesians affected only the contact areas mentioned previously, and in all probability did not involve sailing out of sight of land for distances in excess of about 400 miles. Regular contacts over greater distances were rendered difficult or were prevented altogether by inadequate navigational methods.

Sea voyages to distant islands and island groups were rare and were more in the nature of voyages of discovery which went in one direction only—they were voyages of no return. Navigation back to the point of departure was not possible. The same also applies to voyages which might have been concerned with a destination whose existence was known through tradition or in some other way. The methods of navigation were inadequate and chance alone decided whether such an enterprise succeeded.

Nevertheless, in the course of time, practically every island within Polynesia, no matter how isolated it was, was discovered. Even though this may often have been a result of the canoes being blown off course during local voyages, it is clear that the discovery and colonizing of remote islands and groups of islands was often a consequence of voyages undertaken with the intention of finding new land.

That such voyages could be accomplished in spite of inadequate navigational methods is clear proof of the excellent seamanship of the Polynesians, and of their meteorological knowledge and daring. But this does not explain why they set off on voyages which could last an indefinite period, steering a course into the unknown in the hope of finding a land of whose existence they had no certain knowledge. Behind these enterprises there must have lain compelling motives which induced the Polynesians to sail away towards an unknown fate.

The motives behind the sea voyages

It is probable that within the Polynesian contact areas the motives for the sea voyages were primarily economic. More or less permanent links were established with other islands or island groups in order to exchange goods and services, and people visited uninhabited islands in order to collect foodstuffs or to fish, or even to settle there temporarily to live on what the island had to offer, as long as supplies lasted.

The Tongans collected sandalwood from Fiji, the inhabitants of the Tuamotu Islands sailed to the Society Islands in order to obtain food supplies and stone for implements, the Tahitians sailed to Borabora in order to exchange tapa for coconut oil, etc. (Cf. Denning, 1963, pp. 121—122.)

However, these frequent trading and collecting voyages, which were a firmly established part of the economic life of Polynesian society, never went outside the familiar sailing routes, and they never extended further than reasonably safe navigation allowed. It is probable, nevertheless, that they did make some contribution both to the discovery and colonization of the Polynesian island world and to the maintenance of a certain, albeit sporadic, contact between island groups already occupied but belonging to different contact areas.

When considering what caused the Polynesians to set out on long voyages of discovery and colonization, which took them towards unknown destinations beyond the horizon, we have to look elsewhere for the motives. Peter Buck takes the view that defeat in war was the main reason (1964, p. 218). On Mangareva the losing side were hunted like animals and eaten by the victorious warriors. People preferred the hazards of the sea to the almost certain prospect of meeting death or humiliation on land. Honour was upheld by migrating. The vanquished fled in any craft they could obtain, unless they were lucky enough to be allowed by the victors to gather their families and equip their canoes for a long voyage before being obliged to sail away.

But other compelling motives probably also played a part, for example, starvation, overpopulation and religious persecution. It may also be that now and then ambitious younger sons or chiefs, discontented at not being able to attain a higher rank within the community, organized expeditions and left home in order to acquire new lands and there found

their own chiefdoms. Last but not least, it is possible that the Polynesians undertook long voyages for the sheer joy of discovery and thirst for adventure, and in order to win prestige.

But setting out on a voyage into the unknown does not call only for compelling motives, it also requires confidence in one's own ability to come through alive. Successful colonizers and seafarers lived on in the traditions of their descendants. But there are no stories about voyagers who failed to find new land and perished at sea, because none of those left behind knew whether these voyagers had perished or were still alive on some distant island. Every living Polynesian was a descendant of colonizers who had been guided by one successful navigator after another. In the legends handed down to him there could be no accounts of disasters at sea which struck his own family. This fact created the self-confidence that was needed, together with a sufficiently strong motive, to induce the Polynesians to set out on long voyages of discovery and colonization; voyages, which along with the drift voyages, resulted in virtually the whole of the Polynesian island world gradually becoming inhabited or known. If one accepts these explanations of the migrations, it is not necessary to accept the hypothesis that the Polynesians had accurate methods of navigation unknown and inconceivable to us. (Cf. Hilder, 1963*b*, p. 191.)

Traditions together with the literature about Polynesia, above all that written at an early date, have had to form the basis of attempts to explain what considerations are likely to have provided the main incentive for the Polynesian long-distance voyages. (Cf. Parsons, 1963, p. 38; Denning 1963, p. 121.) Moreover, at this date there is no other way of solving the question of motive.

For natural reasons most of these motives for migration do not exist in the minds of present-day Polynesians. The impact of European civilization has brought about drastic changes in the social structure. Overpopulation and starvation are no longer regulated by war and migrations. The regular trading voyages between the islands have largely ceased. Religious strife exists not between Polynesians but between intruding prophets of foreign extraction, etc.

But despite all this, it has been known for Polynesians, even during our own era, to go off on sea voyages, not just local ones but long ocean voyages. What made them do this? The motives must have been less obvious and demonstrable than in the past, and yet sufficiently strong to make these people sail away at the risk of their lives. The answer must be found in the basic personality structure of the Polynesians, and thus belong to a study of "the psychology of voyaging".

Firth's analysis of the motives for the sea voyages from Tikopia in the

19th and 20th centuries seems to have supplied a fairly satisfactory answer to this problem. The basis of this analysis came partly from carefully selected traditional material, partly from information collected by Firth himself (1961*b*, pp. 150—153).

On Tikopia the habit of voyaging seems to have been a fairly constant element in social behaviour. Sometimes the reason was that the island could not feed the growing population. But of much greater importance were, on the one hand, a feeling of shame and, on the other hand, a thirst for adventure. Men whose self-respect and position in the community had been gravely compromised left Tikopia, as did also those who wanted to see the world. Every generation had its seafarers who set out on long voyages, many never to return. Those who did come home brought with them a knowledge of the outside world, its geography as well as its culture. The majority of these seafarers were young men, many of whom were lost, and so to quote Firth, "the institution of overseas voyaging served as an overflow mechanism for population pressure".

During a period of four generations prior to 1929 more than 100 men set out on long voyages. More than half of them perished at sea, others died in foreign lands, and only about one-third returned to Tikopia. Most of these came home, not in their own canoes, but in mission ships.

Although the sea voyages from the island are a relatively continuous phenomenon, the frequency during certain periods seems to have been considerably higher than during others. During the four generations covered by the investigation, well over half of the voyages took place during a single generation, "... there was almost a frenzy of voyaging overseas". Great fleets of canoes sailed out, and those that were not scattered by storms or sunk had barely returned when they set out again. Firth links this obsession with voyaging with the growing knowledge of the outside world and the exciting experiences offered by the contact with strange people.

A similar peak in the frequency of voyaging was recorded after World War II, when many men left Tikopia in order to seek work or adventure overseas. In about 30 such voyages some 80 men perished, nearly all at sea, and only 20 survived to return home. The inhabitants of Tikopia were well aware of the effect these sea voyages had on the community:

"The loss of men by the many families that suffered ran as a kind of tragic undertone to all the conversations about these adventures overseas. The heavy mortality among the leading men of the island at the peak period of overseas voyaging was expressed in the phrase 'they died travelling' (*e mate saere*). The absence of the chiefs especially seems to have disturbed the people, and the tradition speaks of 'voyages of search' in which prominent Tikopia scoured the islands around in

the hope of discovering the Ariki Kafika in particular, and inducing him to come home." (1961*b*, pp. 152—153.)

But in spite of this, their willingness to undertake sea voyages was unimpaired and perhaps gives an indication of the daring which at one time inspired the Polynesians during the migration periods:

"Fear of storms and shipwreck leaves them undeterred, and the reference in an ancient song to the loss of a man at sea as a 'sweet burial' expresses very well the attitude of the Tikopia" (1961*a*, pp. 32—33).

Certain valid conclusions would seem to emerge from Firth's descriptions.

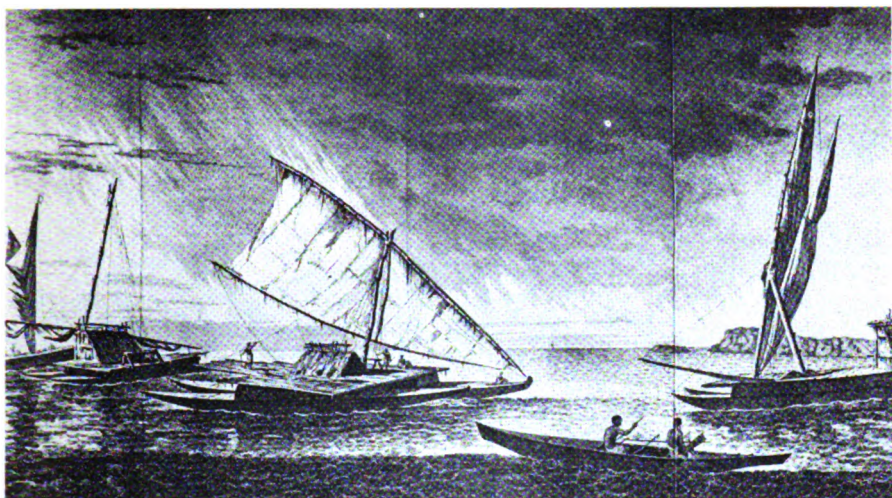
(a) Sea voyages were stimulated by contacts from outside. During historical times these contacts have mainly occurred through Europeans. In pre-European days such contacts with islands or island groups outside the established contact areas are likely to have been few; the Polynesians lacked the navigational and geographical knowledge of the Europeans. In this connection drift voyages probably played a not unimportant part.

(b) During certain periods the sea voyages from Tikopia increased greatly in frequency. The reason for this is unlikely to have been that the contacts from outside during these periods were greater than normal, because on Tikopia such a period seems to have covered about a generation. (According to Firth's methods of calculating a generation is about 25 years.) It is possible, however, that after such an outbreak of voyaging there was such a heavy drain of young, vital and enterprising men that a long time was needed for recovery. The community, of course, suffered both in productive and in reproductive capacity.

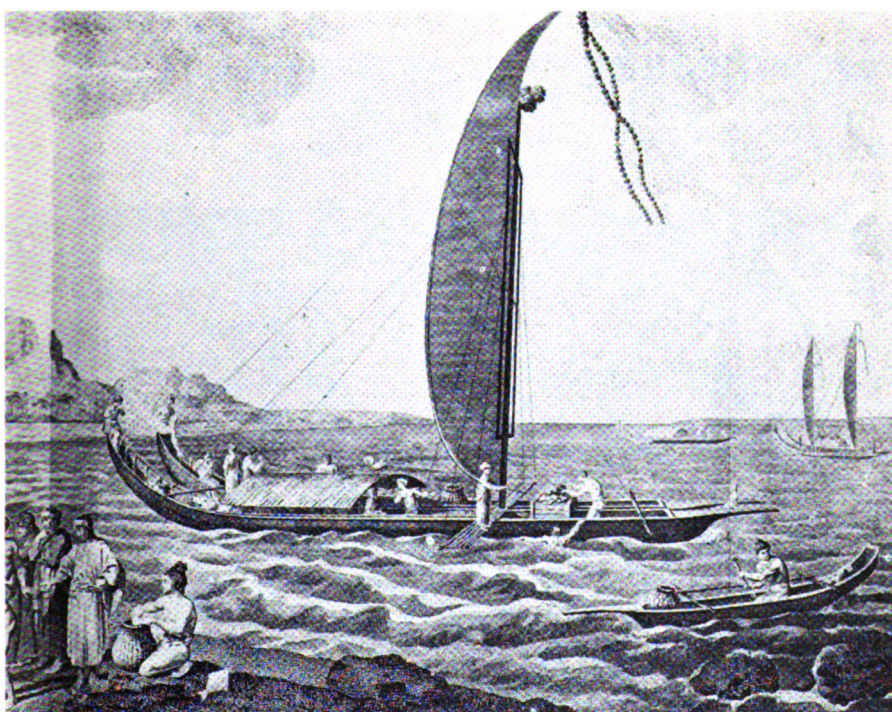
It does not seem to be quite improbable that a similar periodicity in the sea voyages may have been a feature of the pre-European Polynesian community. Then, however, the principal motive for the voyages was not contacts from outside, which are likely to have been sporadic; other fundamental stimuli appeared instead, war, overpopulation, starvation, etc. It is clearly impossible to decide how long a period of time elapsed between these peaks in the frequency of sea voyages, but one can hazard a guess that it was a good deal longer than the three or so generations Firth observed on Tikopia. At that time the sea voyages not only had the character of a male privilege satisfying the love of adventure and increasing prestige, but were concerned with migrations involving no small part of the population and including people of both sexes and of all ages, for whom they represented the sole chance of survival. The population loss was thus a good deal larger than the one witnessed on Tikopia, and

it is also quite likely that a much longer period of time, hundreds of years perhaps, elapsed than was the case on Tikopia, before a new expansion occurred, if in fact it occurred at all.

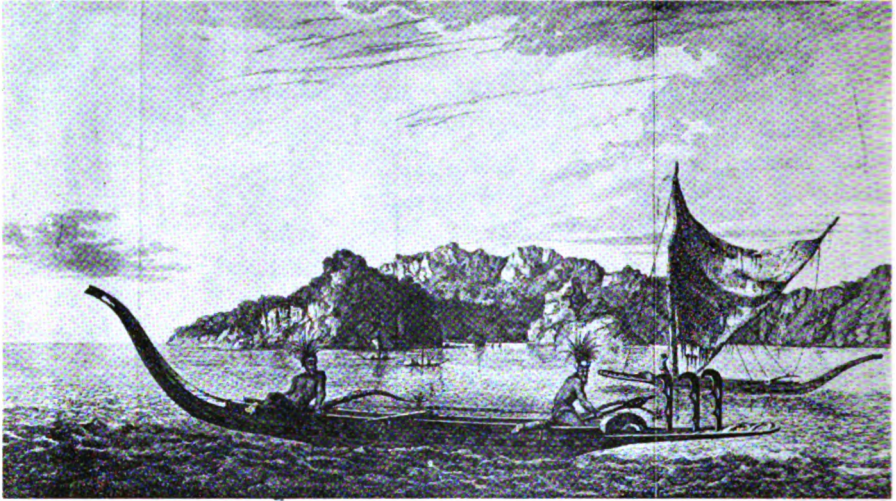
(c) If contacts with the outside world were a stimulus to sea voyages, which is probable, then at the beginning of the post-European era, before the phenomenon of the degeneration of the art of navigation asserted itself, we ought to have been able to expect a considerable increase in the frequency of the Polynesian sea voyages. As we know nothing of the frequency of voyages before the Europeans arrived in the Pacific we lack comparative information of the kind that would entitle us to draw any conclusions. At a guess it is not impossible that the contacts with the Europeans occasioned an increase in Polynesian voyaging, and that what the first Europeans witnessed were not voyages by "degenerate" Polynesian navigators, but those of "average" Polynesians during an expansive period of modest dimensions. At all events it is, as already mentioned, extremely difficult to find support for the hypothesis that in pre-European times the Polynesians were bolder, more skilful and more conscientious long-distance voyagers than they were later on, and that this is to be attributed to an inexplicable degeneration which occurred in the 15th century.



I. Tongan double canoes
(Drawing by W. Hodges. In Cook, 1777.)



II. Tahitian double canoe
(In J. Hawkesworth, 1773)



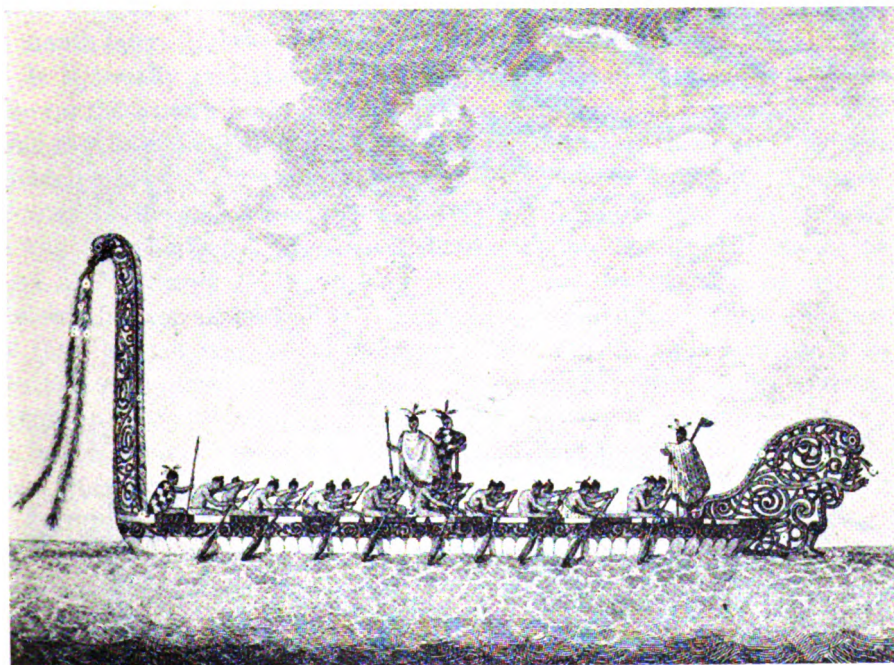
*III. Resolution Bay in the Marquesas
(Drawing by W. Hodges. In Cook, 1777.)*



*IV. Hawaiian canoes bringing presents to Captain Cook
(Drawing by J. Webber. In Cook, 1784.)*



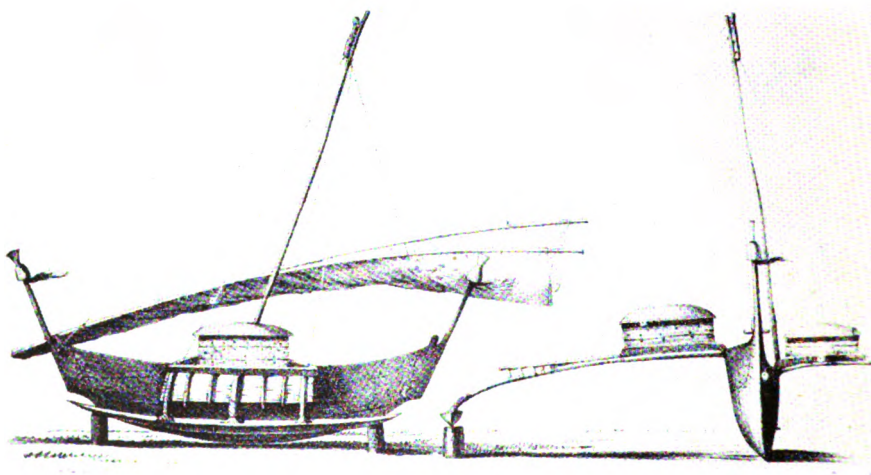
*V. A canoe of the Hawaiian Islands
(Drawing by J. Webber. In Cook, 1784.)*



*VI. A war canoe of New Zealand
(In S. Parkinson, 1773)*



*VII. Sailing canoes of Jaluit, Marshall Islands
(Photo: H. Stolpe, 1884.)*



*VIII. A sailing canoe of the Ratak Group, Marshall Islands
(In L. Choris, 1822.)*

Astronomy and time measurement

It would appear that originally the Polynesian year was divided into seasons, or periods, the beginning and duration of which were determined in various ways. The basis for the division was, within some island groups, constituted by activities which affected the economy of the community, such as the planting and harvesting of yams, while, within others, it might be formed by the beginning and end of the trade-wind period. The time for these events was fixed in relation to the rising and setting of certain constellations. There is no doubt that the Pleiades played much the most important part in this division.

The Pleiades comprise a relatively insignificant constellation located some 24° north of the celestial equator. Its path coincides in the main with the sun's parallel of declination at the summer solstice (on the surface of the earth this is represented by the Tropic of Cancer). The constellation rises at sunset at the end of November and sets at the same time of day at the end of April. It appears again at dawn at about a month later.

It is usually said that the Polynesian year begins when the Pleiades rise on the eastern horizon in the evening twilight (late November). This was the case on Tahiti, among other places, where the year was also divided into two halves and named after the Pleiades (*Matariki*): *Matari'i-i-ni'a*, the Pleiades above (the horizon) and *Matari'i-i-rero*, the Pleiades below (the horizon). The first half of the year lasted from about the end of November to the end of April, when the Pleiades set on the western horizon at dusk. This was also the beginning of the second part of the Tahitian year, which lasted until the Pleiades appeared again on the eastern horizon in the evening. (Cf. Fornander, 1878, p. 116; Henry, 1928, pp. 332; Williamson, 1933, p. 172; Makemson, 1941, pp. 75 ff.)

In this context the term "year" is somewhat figurative, for the Polynesians themselves did not have a name for this concept but instead counted in two or more seasons.

The seasonal division by means of the Pleiades was not, however, uniform throughout the whole of Polynesia. Within certain island groups the year (seasonal division) commenced when the Pleiades appeared on the eastern horizon shortly before sunrise (about the end of May). This seems to have been the case in Pukapuka, Mangareva, the Marquesas Islands (?) and certain parts of New Zealand.

However, the Pleiades alone did not constitute the sign of the beginning of the new year. This was instead indicated by the first new moon after the reappearance of this constellation. This means that the year did not commence on any fixed date, but varied between the end of May and the beginning of June, or late November and early December.

In contrast to what was the case within the greater part of the Polynesian area, the new year on the South Island of New Zealand, in certain parts of the North Island and in the Chatham Islands began, not with the first new moon after the rising of the Pleiades, but after the early morning appearance of the star Rigel (end of May or beginning of June). (Cf. Best, 1922*b* pp. 9 ff.)

In New Zealand the small cluster of the Pleiades reaches a maximum altitude of between 20° and 35° depending on the latitude, while the bright star Rigel rises to a height above the horizon of between 50° and 65° . For this reason it might be expected that the new year was ushered in, not by the Pleiades, but by the more conspicuous Rigel alone. But this is not the case. There prevails in New Zealand both a Rigel year and a Pleiades year, beginning in late May or early June. Makemson considers that this can be explained only by the fact that the first immigrants came from some region of Melanesia with a latitude of about 10° S, where Rigel is about at its zenith, and that they brought with them to New Zealand their old custom of counting years based on Rigel. This year is quite unknown within the rest of Polynesia, and so could not have been brought in by Polynesian immigrants. The East Polynesians, who arrived later, carried with them a Pleiades year that commenced when the constellation rose on the eastern horizon in the evening (late November or early December). The different ways of counting the year used by these two distinct groups of immigrants gradually resulted in the Rigel year being retained within certain areas, while the East Polynesian Pleiades year adapted itself to the time system of the original inhabitants and changed over to commence when the Pleiades rose in the early morning (end of May or beginning of June) instead of shortly after sunset. (Makemson, 1941, pp. 77—79.) (In this connection it is worth noting that both the Pleiades and the Belt of Orion, where Rigel is to be found, have an important part to play in Melanesia as well as Indonesia in connection with economic and ceremonial activities.)

Makemson has examined the myths in search of support for her hypothesis. In so doing she has been able to show that one of the myths about Rangi (Sky-Father), in the form it is retold in New Zealand, is suited to a place north of the equator. The evidence presented in support, which is made on astronomical grounds, seems to be quite incontrovertible. On the other hand, there is nothing to prove that the

myth was brought direct to New Zealand from an area in Melanesia. It is known within other parts of Polynesia as well and so might also have been carried by immigrants from there. Neither archaeological nor linguistic investigations can confirm that there was an immigration from Melanesia. There is instead an indication that there were two approximately simultaneous waves of immigrants from East Polynesia, possibly emanating from Tahiti and the Marquesas Islands. What kind of year these immigrants brought with them it is impossible to tell.

Even though astronomical speculations have not been able to help in explaining the migration routes, it has, however, been possible in this way to demonstrate certain elements in the culture which have probably derived from the area north of the equator.

The Polynesian calendar was based on the phases of the moon and the motions of the stars. The lunar cycle was observed and every night of the lunar month was given a name. (Cf. the Polynesian custom of counting in nights and not in days.) The months were often named after the stars or constellations which dominated the firmament during the months concerned. (There were, however, many deviations from this.) The times for planting and harvesting, for catching fish and shellfish, for sea voyages, etc., were decided by observing the positions of the sun and the stars. The Polynesian island world lies mainly between the two tropics (with the exception of New Zealand and Easter Island) and extends about 50° north and south. As the seasons of the year vary a good deal with the latitude, it was necessary for the Polynesian immigrants in the various island groups to adapt their astronomy and their calendar to local requirements. The result is that the Polynesian calendar is far from uniform. An attempt to give a survey of it would be very extensive indeed and would, moreover, touch on areas which lie outside the scope of this essay.

MICRONESIA

Introduction

Our knowledge of astronomy and navigational methods within the island world of Micronesia is somewhat more detailed than it is for Polynesia. The reason for this would seem, in the first place, to be that the European contact with Micronesia took place later than with Polynesia, and also to the fact that Micronesia was not exposed to the same intensive influence from Europeans that Polynesia experienced. One result of this was that its culture did not undergo such a rapid and sweeping change as did that of Polynesia, and so the ethnographical field investigations have been able to provide material on such matters as astronomy and navigation that is relatively more detailed and unambiguous than the material available in the island world of the south Pacific.

Between the various Micronesian archipelagoes there exist fairly easily definable differences in astronomy and, above all, in navigational methods. On the other hand this knowledge is so uniform within the various archipelagoes—even though certain local variations exist—that it is possible to give a description which is, on the whole, applicable to each of the archipelagoes. From the ethnographical point of view Oliver distinguishes eight culture areas: the Marianas, the Gilbert Islands, the Marshall Islands, the Eastern Carolines, the Central Carolines, Yap, Palau, the South Western Carolines (1961, p. 77). However, in view of the special nature of the subject dealt with here it is not necessary to link the presentation to this relatively detailed division. On the contrary, it seems that a survey will gain in clarity if the accepted geographical division of Micronesia, which is, moreover, more appropriate in this context, is adhered to: the Marianas, the Carolines, the Marshall Islands, the Gilbert Islands. This has accordingly been done, with the exception that the Marianas are excluded. The reason for the exclusion of the Marianas is that the material relating to this archipelago is most incomplete, and that nothing has come to light that suggests that any important additions to our knowledge of astronomy and navigation within Micronesia are to be expected from that area.

Owing to their mixture of Micronesian and Polynesian culture the Polynesian outliers occupy a special position. To the extent that their astronomy and navigation display a definite influence from Micronesian

culture they have been assigned to Micronesia. This applies, for example, to Kapingamarangi, which has been taken as belonging to the Carolinian Archipelago.

In what follows the method of presentation will differ in certain respects from that employed for Polynesian astronomy and navigation. The main reason for this is that the Micronesian archipelagoes must be dealt with one by one, but there is also the fact that the basis is different in character. There is no Micronesian equivalent of the rich Polynesian traditions and myths, and this means that it is not possible to present a picture of the original beliefs concerning the universe and the heavenly bodies, as was the case with Polynesia. In addition, there are no detailed voyaging traditions which can provide a basis for a discussion of navigational methods and of the extent of the sea voyages. The available material consists in the main of ethnographical studies from the middle of the 19th century and later. The information from Micronesia concerning astronomical navigation is more factual and easier to arrange in a scientific astronomical system, but it lacks the temporal dimension which causes Polynesian astronomy to present so many different aspects.

The Caroline Islands

1. General

The Carolinian island chain extends for about 1500 miles east and west. By comparison the north-south spread is small, being at its greatest only about 250 miles. The mean latitude is about 8° N. Apart from Yap and Palau in the west, Ponape in the east and the Polynesian outliers, the inhabitants of the Caroline Islands speak closely related dialects belonging to the same language group, referred to as the Central Carolinian language area. (Goodenough, 1953, p. 2.) Within this area there exists a uniform astronomical and nautical system, which in its final form has spread to other islands within the archipelago. In one respect Yap is an exception, however. Müller has this to say about nautical knowledge on Yap: "Nach Yap scheint nur die Kunde von dem fertig ausgebildeten System gedrungen zu sein" (1917, p. 287). On the other hand Yap has not adopted the Central Carolinian calendar (time reckoning), but has retained its own quite different original one resembling most nearly the one used by the Chamorros in the Marianas (*ibid.*, p. 281).

Even if it is possible to distinguish within the Carolinian island chain certain islands and groups of islands whose culture is substantially different from that of the central Carolines, for the purposes of this survey the Carolines can be regarded as one unit because the nautical-astronomical knowledge throughout is so similar.

Goodenough has pointed out that no cosmogony or astronomical theory has been developed within the Carolines to explain the structure of the universe and the heavenly bodies and their motions, and he also notes that there is no mythology of the stars. In view of the interest the inhabitants display in divination and luck he also finds it remarkable that this has not given rise to an astrological system along the lines of that found within Polynesia. He is of opinion that this may possibly be explained by the importance of astronomy for a seafaring people: "Linked as it is with direction-finding in navigation, native astronomy is perhaps too important for personal safety to permit its being removed from an empirical context" (1953, p. 4).

It is, however, doubtful whether this view can be accepted in full. There are traces of both cosmology and star mythology within the Carolines, even if they are fragmentary and do not appear in the same

profusion as within Polynesia. The interest in ethnographical research in Micronesia got off to a late start, and it is conceivable that traditions and mythology had by that time largely been forgotten. This process would certainly have been hastened by a falling off in voyaging, resulting partly from restrictions on and prohibitions of long sea voyages imposed by the administrators. It is, moreover, uncertain to what extent the ethnographical field researchers took an interest in and reported on these aspects of the culture.

The idea that the absence of an astrological system can be explained by the fact that astronomy was altogether too important for personal safety on sea voyages to permit "its being removed from an empirical context" can hardly be accepted. This situation obtained to at least the same extent within Polynesia, where, nevertheless, a highly developed "astrological system" existed in part.

2. *Sidereal compass*

As the Carolines lie near the equator the paths of the stars are all but at right angles to the horizon. It is thus fairly easy to reconstruct their paths and determine the points on the horizon at which they rise and set. This has enabled the islanders to evolve a fixed orientation system, which makes it possible to determine direction satisfactorily during the hours of darkness. The system corresponds in some ways to a compass, and is therefore usually called the star compass or the sidereal compass.

The east-west axis of this consists of a line which joins the points at which Altair rises above and sets below the horizon. Altair has a declination of 9° N and thus passes through the zenith or in the immediate vicinity of the zenith in all parts of the Carolinian archipelago. The star is the basis of the system of navigation and when it is on the horizon it gives the navigator the direction of east and west. The path of the star corresponds approximately to what is known as the celestial equator in the celestial equator system of coordinates. In this respect, however, the compass is not exact, because true east-west and the celestial equator can be indicated only by a star whose declination is 0° (it passes through the zenith of an observer on the equator). This does not matter to the Carolinian navigator-astronomer because he does not use his compass in the way we use the magnetic compass; he does not give a certain compass bearing but instead gives his course with reference to the point on the horizon at which a star rises or sets.

The north-south axis consists of a line which joins Polaris, just visible above the horizon at these latitudes, with the Southern Cross when it

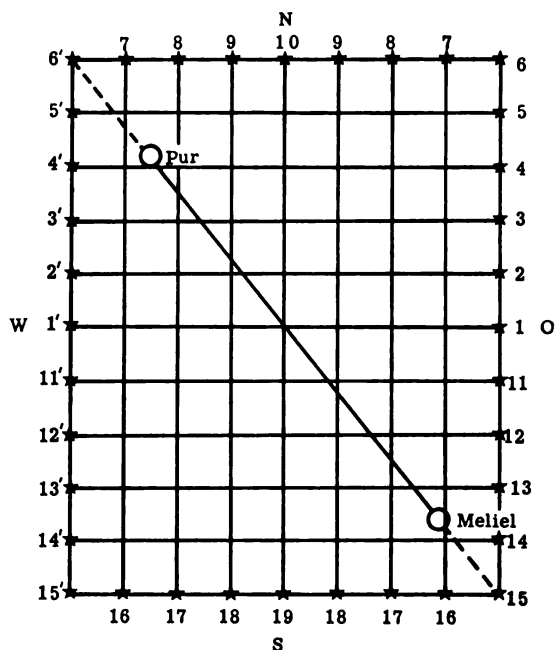


Fig. 7. Sidereal compass, Songosor (after Hambruch, 1912).

is upright (when crossing the meridian). With this the compass indicates true north-south. The great circle between these two stars (constellations) constitutes what we call the celestial meridian, and divides the celestial sphere into an eastern and a western half. The star paths have been given different names in these, depending on whether the star is rising or setting.

With this the framework of the sidereal compass has taken shape. It consists of two axes at right angles to one another, the four cardinal points and the celestial meridian. In addition to the four cardinal points the star compass is furnished with a varying number of other points, indicated by the positions on the horizon at which the stars rise and set. In the Carolines the total number of compass points, which have been named after the stars concerned, varies between 28 and 36. The declinations of the stars (or the bearing to the stars when rising and setting) have been chosen so that the compass points are fairly evenly distributed all round the horizon.

A star compass from Songosor (Sonsorol) is shown in Fig. 7 to illustrate the system. Here account is taken of nineteen stars (constellations) whose rising points (1—9; 11—18) and corresponding setting points are

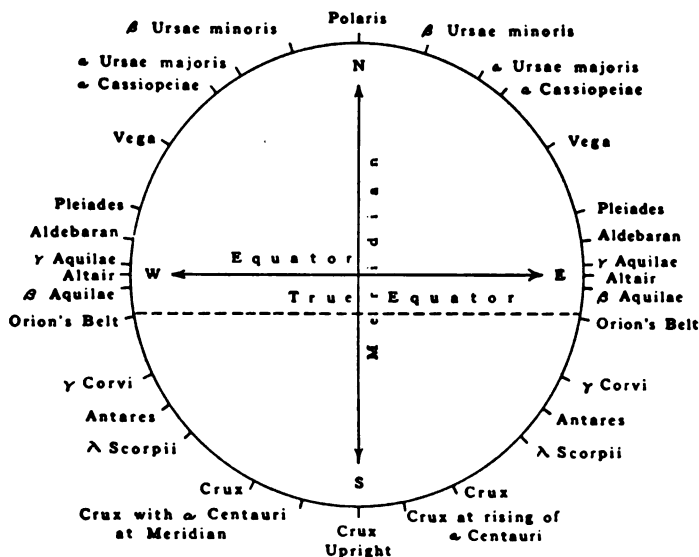


Fig. 8. Sidereal compass, Central Carolines (after Goodenough, 1951).

indicated on the horizon. Number 10 indicates Polaris and number 19 the vertical Southern Cross. The line joining 10 and 19 is the celestial meridian. Number 1 is the point on the horizon at which Altair rises, while 1' is where it sets. The lines joining 1—1', 2—2', etc., represent the paths of the stars.

In general the same stars and constellations are used on all the islands. There are, however, minor differences due to geographical position and the resulting different needs for precision in indicating direction within a certain sector. The east-west orientation of the Carolines means that the longer sea voyages mostly went in these directions. This is also reflected in the sidereal compass in that the compass points are grouped somewhat more closely round the east-west axis, that is to say, a relatively larger number of stars with small declinations is used.

Goodenough has prepared the compass shown above for the central Carolines (Fig. 8), from which it is clear which stars have been selected and what are their rising and setting points on the horizon (1953, p. 6).

The compass stars are not visible, nor do they rise and set at the same time; if they did it would greatly reduce the usefulness of the compass. Instead, the stars have been selected so that during the sailing season several stars can constantly be observed at different heights above the horizon, and their rising and setting points thereby be determined. When selecting stars account has primarily been taken of the suitability for

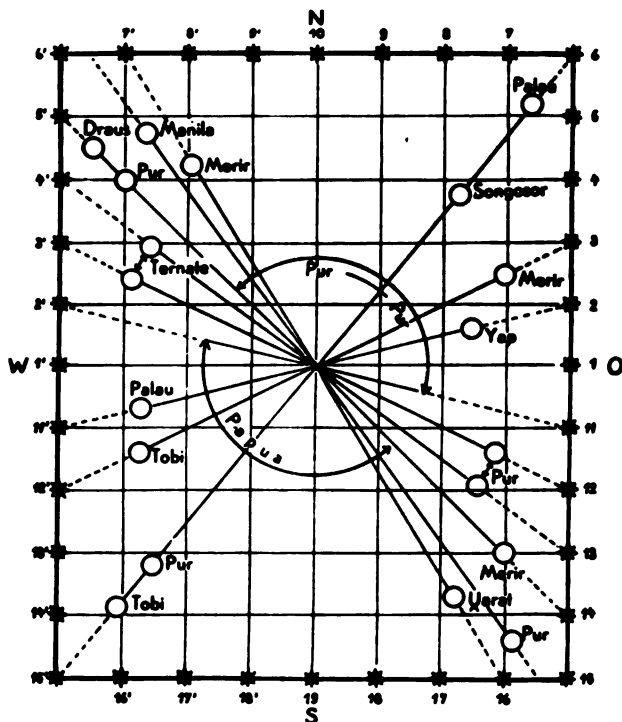


Fig. 9. Sidereal compass, Pur (Pulau-Anna) (after Eilers, 1935).

navigational purposes of their declination and right ascension (rising and setting at different times), so that a favourable spread over the night sky is obtained. The magnitude of the stars has been of minor importance, which means that such bright stars as, for example, Sirius and Rigel are not included in the compass and have not even been named. (Goodenough, 1953, p. 3; Erdland, 1914, p. 78.) On the basis of one or more compass points obtained in this way the navigator can reconstruct the whole of his sidereal compass. Its usefulness is not therefore dependent on the observation and position of all the stars included in the compass. For example, the compass point "Altair" is fixed irrespective of whether that star is visible or not.

If the sidereal compass is to be of practical value, the islands known by the navigator must be placed in relation to it, that is to say, the course to the destination has to be given in relation to one of the compass points.

For a voyage between Pur (Bur) and Merir (Meliel) course is set from the point on the horizon where the star 5' sets to the point where

the star 14 rises (Fig. 9). The chart does not give the true geographical position of the islands, because the course directions have taken account of leeway and set and drift with the current. The navigator imagines himself as always being in the centre of the chart. No "charts" in the real meaning of the word exist, however. The one reproduced here is merely an ethnographical reconstruction designed to explain the principle of navigation. The Carolinian navigator was obliged to memorize the compass, the positions of the islands in relation to it, and also the necessary course directions. That these latter could amount to a considerable number is shown by the fact that on Puluwat Sarfert was informed of no fewer than 100 of them (1911, p. 134). The directions included the estimated number of days for the voyage and also gave the course direct to the destination as well as via a third island, which could serve as an alternative landing place in the event of bad weather. Together with the other two, this third island formed a triangle and served, according to Sarfert, as a "Notinsel" (1911, pp. 135—136).

As is shown in Figs. 8 and 9 the sidereal compass is in one case reproduced as a rectangle and in the other as a circle. The first complete information about the compass was supplied by Sanchez y Zayas (1866, pp. 263—264), and in accordance with the express instructions of the informant the compass was drawn up in the shape of an irregular rectangle. The German ethnographers reproduced the sidereal compass in a similar way. From a practical navigational point of view, however, it does not matter whether the Carolinian navigator conceived of the horizon as a rectangle or as a circle.

It has been mentioned earlier that Altair indicates the east-west axis of the star compass, which means that this axis is correct only at a latitude corresponding to the declination of the star, that is to say, 9° N. If one leaves this latitude and goes north or south the bearing to the points on the horizon where the compass stars rise and set will be changed. The further one goes away from the mean latitude the greater will be the change. In other words the compass will be misleading. However, the directional change is not uniform, but is least in respect of stars which rise and set near the east and west and increases towards the northerly and southerly points. Polaris and the vertical Southern Cross always indicate true north-south, however, and a star with a declination of 0° always indicates true east-west, irrespective of latitude.

As the compass error occasioned by latitude changes increases more quickly on north-south courses than on east-west ones, this means that the compass can be used within wider latitude limits on east-west courses than on north-south ones. For example, if the desired compass accuracy is 1° and the compass course $< 45^{\circ}$, the latitude area within which

the desired degree of accuracy can be attained is about 11° (about 700 miles). (Cf. Frankel, 1962, p. 42.) Courses between 45° and 135° , on the other hand, can be steered for much greater distances.

It is not possible to make a direct comparison between the use of the star compass and that of the magnetic compass. A magnetic compass indicates (with certain corrections) the true course expressed in degrees, irrespective of latitude. On the other hand, the task of the sidereal compass is not to give true bearings but to indicate courses to be steered in relation to known geographical points. Consequently, it consists partly of a fixed number of points on the horizon where stars rise and set, and partly of the positions of the known islands and atolls in relation to those points. If the Carolinian navigator knows that there is another island group a long way outside his own archipelago, and he is aware of its position in relation to the sidereal compass, he can (in theory) reach this group by steering towards the rising or setting point of the star which indicates the course to the island group in question. If, during the voyage, the latitude change has been considerable, the direction to the star's rising/setting points will also have changed and the compass will indicate directions other than those in the Carolines. However, a change in latitude will also mean that certain stars drop below the horizon, while others rise above it. In that case the navigator must therefore replace the stars located towards the poles by new ones, and in addition he must adjust the compass to take account of the fact that the directional change in the rising and setting points of the stars has not been uniform. It is necessary for him to construct a new compass in relation to whose points the relative positions of the islands in the new archipelago are given.

3. The sun and its motion

The position of the sun in the ecliptic was given with reference to the constellation it was in at sunrise. The months (varying in general between 12 and 18) were often also named after these constellations. There were local variations in this respect, however. For instance, Krämer says that on Lámotrek the months were instead named after the stars which rise at midnight, that is to say, those which reach their zenith in the early morning (1938, p. 133).

However, the sun's annual motion not only formed the basis of the calendar, it also made possible a reconstruction of the sidereal compass and a checking of the course steered at certain times during the hours of daylight. This was done by observing at which compass point the sun rose and set and by reference to this, determining, first, the compass points of Altair, and then the other points (Eilers, 1935, p. 84).

As the sun's path varies in relation to the stars, its rising and setting points on the sidereal compass will constantly change. The navigator thus had to know where these points were on the compass throughout the year so as to be able to reconstruct his compass with the help of the sun. In his account of the astronomy of the Gilbert Islands Grimbale states that the sun's position at sunrise was fixed at 10-day intervals (1931, p. 206). In view of the unanimity of the information from the Carolines concerning both the observations of the sun's annual motion and its importance in navigation, it does not seem altogether unreasonable to assume that a similar periodic determination of the points at which the sun rose was also made within the Carolines. Observations made at such intervals will cause an error in the true bearing to the rising (setting) sun of not more than about 4° . This will happen at the time of the vernal and autumnal equinoxes, when the change in the declination of the sun occurs most rapidly. Around the time of the winter and summer solstices the error is negligible.

The accuracy of the reconstruction of the sidereal compass by means of the rising and the setting sun, as observed at 10-day intervals, can be considered quite adequate for navigation within the voyager's own archipelago. According to Hambruch the course could also be checked when the sun was on the meridian, that is to say, when it reached its maximum altitude. The shadow cast by the mast at that moment indicates true north-south (the compass points for Polaris and the Southern Cross), and the navigator would then have an opportunity of reconstructing his compass and checking his course. (Hambruch, 1912, p. 23.)

4. Meteorology

To accomplish a sea voyage, whether long or short, the navigator not only has to know how to steer the intended course, he must also be able to decide, with respect to weather and wind, what is the most suitable period of the year for embarking on a voyage, and also what winds and currents he can expect to meet during the voyage. Owing to the relatively stable weather conditions that prevail within these regions of the Pacific Ocean it is possible for the navigator to forecast the meteorological factors to some extent. Within the central Carolines the year is divided into 18 or 19 periods of varying lengths, based in the main on the helical rising of certain stars or constellations. (These agree only partially with those included in the sidereal compass.) By setting the weather conditions in relation to these stars there has been developed a "navigator's almanac", in which attention has mainly been given to indicating as carefully as possible the time at which the weather changes and those

periods of the year during which the weather is stable. With the help of this almanac it was possible for the navigators to decide when voyages to various islands were possible and appropriate, what winds and currents would be prevailing and how long they could be away before having to start for home (cf. *inter alia*, Goodenough, 1951, p. 109 and ESE II). Krämer has reproduced an exhaustive table for Lámotrek, which gives the relationship between stars (constellations) and the direction and strength of the wind at 25 points of time all round the year. This table notes, for example, that when Antares rises in December the winds are so strong that ocean voyages are impossible. This is in close agreement with the suspension of ocean voyages to other islands during the period from mid-October to mid-January which Burrows has reported from Ifaluk (1937, p. 87).

From the end of November the trade wind sets in and blows steadily from the east until the end of May. To start with, the wind is too strong to permit a safe voyage and Kubary reported that the navigators consequently preferred to wait until towards the end of the period, by which time it had dropped enough to afford a weak but steady sailing breeze (1880, p. 288).

The times when the wind shifted, at the beginning of May and at the end of September or early October, offered many advantages from a sailing point of view. A canoe which sailed westwards with the trade wind in May could expect to have good westerly winds for the voyage home, without needing to wait, perhaps for months, for a suitable wind. (Burrows & Spiro, 1957, p. 87.)

5. *The voyage*

Prevailing winds and currents were thus decisive for the determination of a suitable time of year for voyages to various destinations. When sailing over long distances the voyage was made in stages, and adjacent islands were visited, even though this entailed deviating from the direct route to the destination and increased the total sailing time. The courses were steered with the help of the sidereal compass, and the positions of the islands were given in relation to the compass. The system was flexible. Different winds and currents prevailed at different periods of the year and so the positions of the islands given in the compass were altered to take these changes into account. In other words, the compensation made for displacement was performed on the basis of experience (Eilers, 1935, p. 241).

When the sky was overcast, so that the sun and the stars could not be observed, it was also impossible to use the sidereal compass, and so the

sail was lowered and the canoe allowed to drift (Damm, 1935, p. 94). The same procedure was followed in stormy weather. The navigators from Songosor, however, continued their voyage when the heavenly bodies were obscured, keeping on course through observing the direction of the easterly swell which prevailed throughout the year (Eilers, 1935, p. 85). Knowledge of the prevailing swell also played an important role when making landfall. If the swell meets an island or reef it is reflected back from it and the sea which results is noticeable a long way from land. On the leeward side the refracted swell produces a characteristic sea, which helps the navigator to decide whether he is near land. (Damm & Sarfert, 1935, p. 105.)

It was mentioned earlier that the courses were corrected with regard to the ocean currents. Burrows has given an account of the technique followed on Ifaluk when the direction of the current was being measured. When the canoe had got far enough out from land to be free of the influence of the local currents, the sail was lowered and several lines with sinkers on were paid out over the side of the canoe. Tied to each line there was a palm leaf, which was to act as a current indicator (analogous to a weather vane). The palm leaves sank so deep in the water that they were only just visible from the surface. The current then swung the leaves so that they pointed in the direction in which the current was flowing. (Burrows & Spiro, 1957, pp. 97—98.) However, with this method it is not possible to determine the true direction of the ocean current as it also affects the canoe during the measuring. Thus it appears that Burrows may have misunderstood his informant in this case.

Latitude and longitude cannot be determined by means of the Carolinian sidereal compass. As already stated, it is unlikely that in Polynesia the latitude was determined by observation of a zenith star. On the other hand, the method has never been attributed to the navigators in Micronesia and there is no discussion of the method in the literature dealing with this region. Strangely enough, however, it so happens that the only existing reference to the use of a zenith star for determining position is, so far as I know, one given in an account of sea voyages in the Carolines. The information is supplied by Sanchez y Zayas, the Spanish seafarer who visited Micronesia, mainly the Marianas, in the middle of the 19th century. While he was staying on the island of Tinian (near Saipan) a canoe arrived from Elato in the central Carolines. From the navigator on board the canoe Zayas obtained the following information about Carolinian navigation:

“They shape their course by the sun, the stars, the direction of the wind,

or that of the waves. If the weather inclines to be foul, the sky becoming cloudy and continuing so for some days, they lay by for the coming storm, and when over the helmsmen tell me that three days are necessary to get to the eastward what they have lost. Then they have recourse to their observations: they fill a cane with water and observe the stars in the zenith, and thence study the position of the vessel. This ascertained gives them their course, and they prosecute their voyage." (1866, p. 263.)

The mention of a zenith star is interesting, but it is difficult to decide what value to attach to it, since there is no confirmation from any other source. The account also contains a statement of very questionable accuracy, which means that its reliability ought not to be taken for granted. This is the reference to the canoe laying by during the storm and then needing three days in order to fight its way eastward so as to make up for the time lost through drift. Why three days, and why eastward? The account is of such a general kind that the information seems suspect, which, on the other hand, would not have been the case had it referred to a special occasion.

The use of the bamboo cane filled with water for astronomical observations is, however, nothing new in "primitive astronomy"; witness for example the way in which certain Dayaks in northern Borneo determined the right time for sowing. They used

"a bamboo some feet in length, which bears a mark at a level which is empirically determined. The bamboo is filled with water while in the vertical position. It is then tilted till it points towards a certain star, when of course some water escapes. After it has been restored to the vertical, the level of the surface of the remaining water is noted. The coincidence of this level with the mark mentioned above indicates that the time for sowing is come." (Hose & McDougall, 1912, p. 109.)

Unfortunately Zayas' description does not give us any details of the procedure followed when observing a zenith star with the help of a water-filled bamboo cane. It seems more likely that the navigator observed a heavenly body at a lower altitude than a zenith star and measured the altitude in essentially the same way as the Dayaks of Borneo. Zayas' account of a zenith star is probably a result of his misinterpreting what his informant told him.

As already noted, the Carolinian sidereal compass could be regarded as accurate for the whole of the archipelago, but that its error increased the further one went from the mean latitude of the compass. The distance from Elato to the nearest island in the Marianas, Guam, is over 350 miles and the course is slightly west of north. By taking into account only the change in latitude the compass could therefore also be used for such

a voyage. Added to this, however, is the fact that the Marianas extend a long way north and south, whereas the distance from east to west is very short indeed. In general, the islands lie like a string of pearls running north and south, i.e. at right angles to the main extent of the Carolines. A canoe sailing from the central Carolines to the Marianas will thus steer almost due north towards a destination presenting a very narrow target. The danger of sailing to one side of the destination is considerable and the advantage of latitude sailing in order to facilitate landfall is apparent.

North of the equator the latitude can be fixed simply and reliably by measuring the altitude of Polaris. This altitude is very nearly the same as the latitude of the observer. (1000 years ago, however, Polaris was about 5° from the pole.) Determining latitude by means of observations of Polaris also has the advantage that in clear weather it can be performed several times during the hours of darkness, whereas the zenith star indicates the latitude only at the moment it is at the observer's zenith.

Elato lies at about latitude 7.5° N, Guam at about 13.5° N and Saipan at 15° N. A canoe which sails to Guam or Saipan from the central Carolines must therefore sail so far north that the altitude of Polaris is measured at 13.5° and 15° respectively. It is conceivable that it was for this altitude determination that the Carolinian navigator made use of the "bamboo sextant" mentioned by Zayas. At all events it is a good deal more credible that the navigator determined the latitude by observing Polaris than by observing a zenith star. As against this, it seems doubtful whether it is, in practice, feasible to obtain sufficiently accurate values by measuring the altitude with such a water-filled bamboo cane in a canoe on the high seas. It may be asked whether equally good, or better, values could not have been obtained by making use of the instrument constituted by the navigator's own hands. (Cf. Eiler's description of taking bearings and measuring the altitude of heavenly bodies in the western Carolines. 1935, pp. 84, 364.)

It may seem that this discussion of possible determinations of latitude within the Carolines has been given a disproportionate amount of space. It is, however, of no little interest to find out whether and, if so, how the latitude was determined in "primitive" celestial navigation, as ability to determine latitude considerably increases the reliability of navigation. Zayas' account, which has been paid no attention hitherto, is also the only one from the whole of Polynesia and Micronesia which gives a real hint that heavenly bodies were used by the navigator for the determination of latitude. Granted that the information is vague and cannot be given an unambiguous interpretation, it does, nevertheless, seem to be of such a nature that it cannot be passed over without comment.

6. Summary

The sidereal compass indicates only what experience has shown to be the proper course to be steered having regard to the position of the destination, leeway and set and drift with current. The uncertainty factor when navigating by this method is large even over the relatively short distances involved in voyages within the Carolinian island chain. Furthermore, there is the fact that the islands within the Carolines are, with few exceptions, very low-lying and therefore not visible at great distances. The voyages were therefore carried out in stages wherever possible, landfalls being made on islands which lay close to the route, so as to reduce to a minimum the time spent out of sight of land. Thus a voyage from Ifaluk to Truk, some 425 miles, went via Elato, Lámotrek, Satawan, Puluwat and Souk, the longest stage being one of about 125 miles. (Burrows & Spiro, 1957, p. 339.) By means of the sidereal compass the navigators are still in a position to reach nearby islands "most of the time, though being lost at sea is unquestionably one of the people's haunting fears" (*ibid.*, p. 92).

In good weather conditions the Carolinian navigational methods work well and a skilful navigator is said to be able to make land with good precision. But if the canoe is forced to lay by owing to bad weather, or is becalmed, it will then be subjected to a drift which the navigator cannot influence and whose direction he cannot determine. The Carolines lie within the two opposed equatorial currents, whose directions, particularly during periods of calm, are variable and whose limits relative to each other are not fixed. A canoe which has been subjected to drift through current and wind for a long time will therefore have been carried to an unknown position, and the seafarer's methods of navigation will not enable him to determine this position and in what direction he must sail in order to reach land.

The fundamental reason for this is that the navigation, like all primitive navigation, is based on dead reckoning, that is to say, an assessment of the position through an estimate of the course and distance made good, compensated for leeway and set and drift with current, made on the basis of experience. Therefore, if the movement along the course line is interrupted and the canoe is forced off course by an uncontrollable influence, then when it is possible to resume the voyage the navigator is unable to determine his new position and the new course to be steered. He has no fixed reference point for his compass because he cannot determine his longitude or, in all probability, his latitude either, except very roughly. The sidereal compass can no longer be used, as the position of the canoe, which has to be its central point, is unknown, and con-

sequently so also are the positions of the islands. The navigator has gone completely astray at sea. (Cf. Gladwin, 1958.)

It is not possible at this date to decide the extent of the early sea voyages. The sailing directions collected by the German ethnographers within the Carolines cover wide areas and, in addition to that archipelago, also embrace islands in the Philippines, the Marianas, the Marshall Islands and off northern New Guinea (Sarfert, 1911, p. 134). It would appear likely, however, that this extensive knowledge of distant regions has for the most part been acquired in recent times through European influence. At all events speculation on this problem can in no way help to throw light on the islanders' navigational methods. All one can say is that it is improbable that regular contacts were maintained over distances as great as those in question here; the navigational methods were too inaccurate for that.

The Marshall Islands

1. General

The Marshall Archipelago consists of about 28 atolls and four islands lying in two parallel chains, Ralik and Ratak, and extending over 600 miles in a NW—SE direction. The distances between neighbouring atolls within each of the two island groups are fairly short and do not exceed about 85 miles. The greatest distance between Ralik and Ratak is about 130 miles. However, navigation within the archipelago is made difficult by the fact the islets are mostly very low and can be sighted only at short distances, and also by the fact that the main direction of the trade wind and the equatorial currents cuts right across the longitudinal axis of the Marshall Islands. As communications took place mainly within the island chains themselves this meant that while moving along north-south courses the canoe would be greatly affected by wind and current. Ocean currents and local currents are both strong and variable, and this adds to the difficulty of estimating the canoe's displacement.

Navigation within the Marshall Islands, like that within the rest of Oceania, was based on astronomical knowledge. Along with this, however, there was developed a system of navigation that is quite unique. This system is based on a careful observation of the changes in the direction and configuration of the swell and the waves, which come about when these meet the atolls in the archipelago. These changes cause certain characteristic observable phenomena, through which the navigator can indicate the direction to land that is out of sight and determine his position in relation to surrounding islands. The navigators of the Marshall Islands displayed their knowledge of swell and wave phenomena in their widely discussed navigational charts, or "stick charts" as they are often called.

2. Astronomical navigation

In the study of navigation within the Marshall Islands interest has generally been concentrated on the navigational charts and on attempts to interpret them. For this reason our information about the islander's astronomical knowledge and about the way in which the heavenly bodies were used for navigation is rather limited.

Polaris and the Southern Cross, which are visible in most parts of the Marshall Islands, indicate true north-south for the navigator and constitute

the fixed points in an orientation system. Erdland states that if these stars were obscured by cloud, the navigator used two other stars, σ Sagittarii and β Libræ, in order to determine north and south. A line drawn through these two stars towards the pole, Erdland adds, would pass through the position of Polaris and in this way indicate true north. (1914, pp. 85, 89.) This statement is incorrect, however. The relative positions in the firmament of these stars are such that a line drawn through them does not by any means indicate north. Consequently they cannot have been used for the determination of direction mentioned by Erdland. His statement must be based either on an incorrect identification of the stars or on a misinterpretation of his informant's statement. In spite of the fact that this item of information can easily be checked it has been quoted by other ethnographers.

The course was steered with the help of horizon stars, in accordance with the principle previously described in detail in the discussion on Polynesian navigation. When voyaging from one atoll to another the course was usually set from one fixed point or headland to a corresponding point on the other atoll. The course was indicated by stars rising over these points. The navigator knew how long he could steer by such a star before its azimuth change made it necessary for him to replace it by another one. (Erdland, 1914, pp. 80—81.) Erdland has also stated which guiding stars were used on a number of different voyages within the Ralik group. The information is incomplete, in so far as only one star has been allotted for each voyage.

According to Davenport it was necessary for the direction to the steering star to coincide only roughly with the true course. The experienced navigator knew how much he needed to allow for the difference between these, and he also knew how much to compensate for leeway and set and drift with current. (1960, p. 19.)

3. *Navigational charts*

The existence of navigational aids, known as "stick charts", of a kind that is unknown outside the Marshall Islands, was reported for the first time by Gulick, the American missionary (1862, p. 304). Being, as they were, one of the few examples of primitive cartography they aroused great interest right from the start, and much effort has been devoted to interpreting their true meaning. After detailed field studies the principles on which the charts were constructed and used were explained by Winkler (1898, p. 1418, ff). These investigations were supplemented by Schück, who assembled and analysed information concerning all the chart material then known (1902). Further attempts have been made to interpret the

charts, but these have hardly made any essential contribution to our understanding of them.

The stick charts consist of a more or less complex network of sticks (palm ribs) bound together with strings made from coconut fibre. Sea shells and small pieces of coral are often fixed to the sticks in order to represent the atolls of the archipelago. However, the charts are not sea charts in our meaning of the term, because in most cases their main purpose is not to give an exact geographical picture of the island world. The primary aim of the navigator-cartographer is to illustrate swell phenomena in the neighbourhood of the atolls and the positions of the atolls in relation to these phenomena. His interest in the actual distances and directions between the atolls is a secondary one only. Although the principles underlying the stick charts are the same throughout, charts referring to one particular area can vary widely both in scale and in construction. The fact is that the charts are an expression of the personal knowledge and experience of the different navigators, which are kept strictly secret and not circulated outside the immediate family. For this reason a full interpretation of a chart is often possible only with the help of its constructor.

The charts were not taken on board during sea voyages, nor were they used, as western sea charts are used, for laying out courses, plotting bearings or as an aid in identifying a coast. They are, instead, to be regarded as a means of storing navigational information already obtained.

(1) Principles

The phenomena which the navigator observed and which helped him to indicate the position of and the direction to an atoll still out of sight, are the refraction and reflection which occur when a swell meets land. (Cf. Davenport, 1960, pp. 20—21.)

(a) Refraction. As the swell nears land and the water becomes shallower the speed of the inshore ends of the waves is reduced in relation to the offshore part of the swell which is moving in deeper water. The result is that the inshore portion of the swell changes direction and tends to follow the contours of the shoreline. On the lee of the island the change in direction can exceed 90° and give rise to a cross swell. The size of the refraction will depend on the length and height of the swell, the shape of the island and the depth of the sea around it. A strong swell moving towards a circular island or atoll will result in a marked refraction and a characteristically turbulent "shadow", which is noticeable a good many nautical miles out at sea from the leeside of the island.

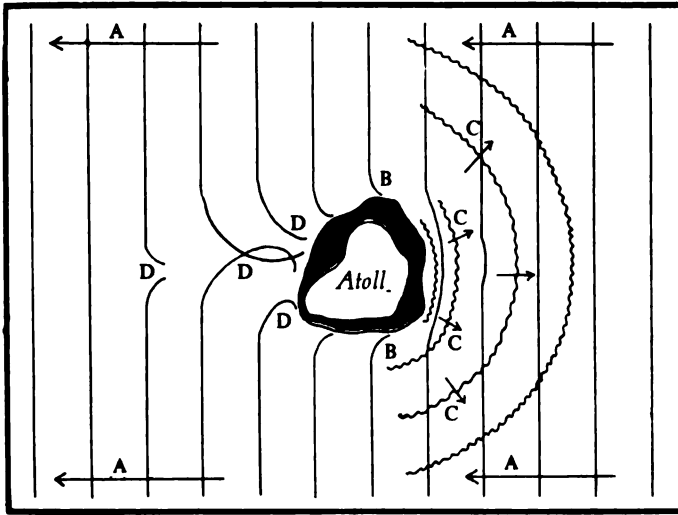


Fig. 10. Refraction and reflection of ocean swell. A, direction of swell; B, refracted swell; C, reflected swell; D, shadow of turbulence. (After Davenport, 1964.)

(b) Reflection. Part of the swell is reflected by the shoreline. These reflected waves differ in appearance and direction from those of the swell.

Within the Marshall Archipelago the swell can be observed from four main directions:

- Easterly swell.* The strongest. Can be observed in all parts of the archipelago throughout the year.
- Westerly swell.* Weaker than the easterly swell, but can be observed all the year round by an experienced navigator.
- Southerly swell.* Weaker than the easterly swell. Mainly to be observed in the southern regions of the archipelago.
- Northerly swell.* Weaker than the easterly swell. Mainly to be observed in the northern regions of the archipelago.

The easterly swell and the westerly swell are both divided by an atoll into north and south arms by means of refraction (Fig. 11).

When the northerly (southerly) arms of the two swells intersect at a certain angle the waves become peaked and broken in what is called a *bot* (node). The narrow sector within which the nodes are visible is called the *okar* (root) and extends north and south of the atoll. (It is called *okar* because just as one finds a tree if one follows its roots, so one will find the island on which it grows if one follows the sector

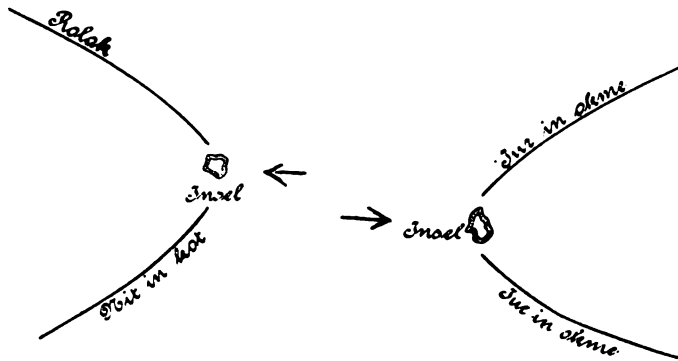


Fig. 11. Refraction (after Winkler, 1898).

where the nodes are seen.) At a certain distance from land the angle of intersection between the swells is at its maximum and it is here the nodes are most in evidence. As one approaches land this angle diminishes, but the refraction increases and with this the extent to which the intersecting swells deviate from their original direction. By following an *okar* and observing the changes in the direction and angle of intersection of the swell, the navigator is able to determine whether he is nearing land or getting further from it. A navigator who has not reached an *okar* can, by observing the direction of the swell, decide whether he is to the north or south of the atoll (Fig. 12).

The northerly and southerly swells can be used for navigation in a similar way.

The Marshall Islands charts can be regarded as models reproducing the phenomena described above. It is probable that certain constructional details on some charts ought to be interpreted as a direction concerning the position from which an atoll could be sighted.

Some ethnographers, mostly German (Krämer and others), have maintained, however, that the charts also contain information relating to the ocean currents. In his pioneer investigation Winkler, on the other hand, has emphasized that this is not so (1898, p. 1422) and his view is also shared by Davenport (1966). There seems to be no reason to object to the views of these two scholars.

(2) Types of chart

The charts fall into three main groups:

Mattang Chart for instructional purposes, designed mainly to illustrate the phenomenon of refraction.

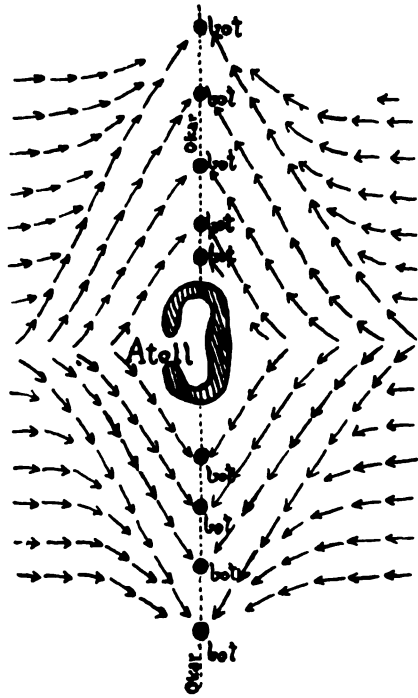


Fig. 12. Bot and okar (after Krämer, 1906).

Meddo Chart of a certain part of the archipelago. Indicates the relative positions of the atolls and gives certain details concerning prevailing swells.

Rebbelib Chart of the whole archipelago or of one of the two atoll groups Ralik and Ratak. Contains few details relating to the swells.

(a) *Mattang*

The construction and use of the navigational charts is best explained by describing a *mattang*. These exist in a number of different versions, but the one shown in Fig. 13 seems to be a type in more general use and so it has been selected by way of illustration. Various interpretations of it exist, but on the whole these differ only in certain details. Davenport's presentation has been followed in Fig. 13. (1960, pp. 22—23.)

The chart is orientated with reference to the direction from which the dominant easterly swell comes. This direction is indicated by the line (the stick) R^1 — R^2 .

The chart can be used in order to illustrate the appearance of the swell in the vicinity of one or more islands.

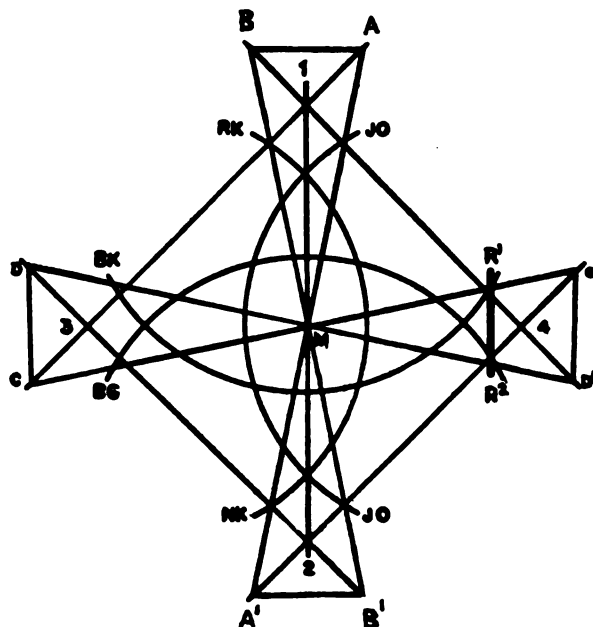


Fig. 13. Mattang (after Davenport, 1960).

(i) M denotes an atoll at the centre of the chart.

The easterly swell is refracted in two arms by the atoll M, a northern one, RK, and a southern one, NK. Similarly the westerly swell is refracted in a north and a south arm, both JO. The weaker swells from the north and south are denoted by BG and BK.

When the easterly swell, RK—NK, meets the westerly swell, JO, at a certain angle, the intersecting waves peak and may break, a *bot* (node) is formed. The nodes extend along a narrow sector, an *okar*, north and south from M. The line 1—M—2 represents this *okar*. The nearer one approaches the atoll M along the *okar*, the smaller is the angle between the intersecting swells, and the greater the refraction.

The northerly and southerly swells can be used in a corresponding way.

(ii) The points 1 and 2 represent atolls due north and south of one another. The line AM denotes the easterly swell and the line BM the westerly swell for atoll 1, while B¹—M and A¹—M indicate the corresponding swells for atoll 2. The line 1—2 is the direct course between these atolls and also the *okar* which joins them. A navigator who sails from 1 to 2 therefore follows the nodes in the *okar* from 1 as long as they are visible. He then continues the same course until the nodes in the *okar* from atoll 2 are visible, after which he follows these until he reaches 2.

If a current sets across the course line the navigator compensates for this by following the curved line RK—NK or JO.

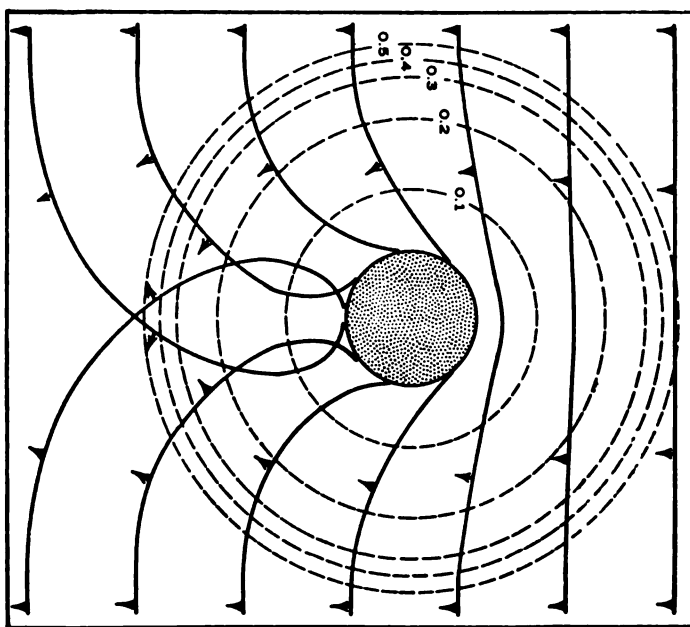
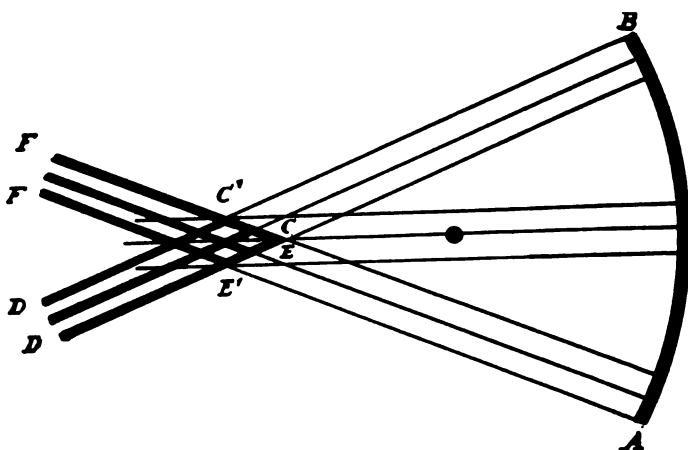


Fig. 14. Mattang and modern diagram illustrating refraction (after Jeschke, 1906, and H. O. Pub. no. 602, 1939).

According to Winkler the main function of the sticks CA , BD^1 , C^1A^1 and B^1D is probably only to form the framework of the chart, but they could also be used to denote swell (1898, p. 1426). Thus $C-1-D^1$ gives a northerly swell for atoll 1, and $B-4-A^1$ an easterly swell for atoll 4, etc.

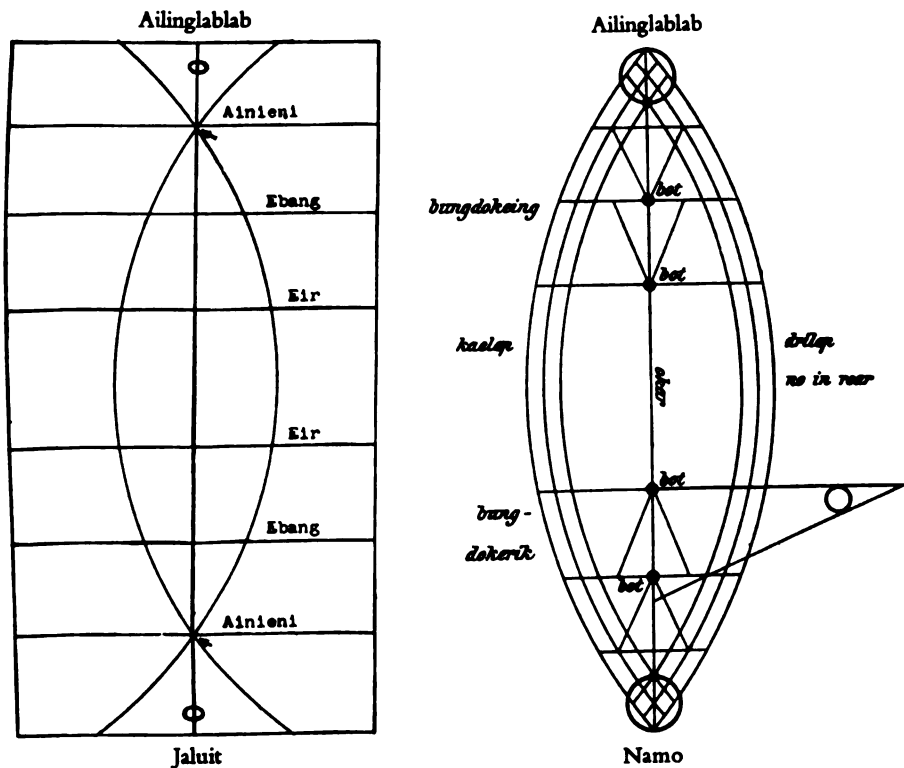


Fig. 15. Meddo (after Stolpe, 1884, and Krämer, 1906).

Further variations in the illustration of the phenomena of swell are obtained by allowing the points 1, 2, 3 and 4 to represent four different atolls.

A *mattang* of a simpler type, intended only to represent the appearance of the swell on the leeward side of an island, is seen in Fig. 14.

Finely drawn lines indicate sticks which form the framework of the chart. They are of no importance in the interpretation.

The arc A—B indicates the easterly swell, the lines C—D, E—F etc., show how the north and south refracted arms of this swell intersect on the leeward side of the atoll. Compare the extent to which this agrees with the same phenomenon as presented theoretically in modern hydrography.

(b) Meddo, rebbelib

The principles underlying the phenomena of swell, which were illustrated by means of the *mattang*, found their application in the construction

of the charts which supplied the actual navigational directions, *meddo* and *rebbelib*.

In the Ethnographical Museum, Stockholm, are one *mattang*, one *meddo* and 16 *rebbelib*, which were brought from Jaluit by Stolpe in 1884. (A further nine *rebbelib* had been found earlier.) Although detailed information concerning these charts is not available it is possible, with one exception, to offer a theoretical interpretation of them by making a comparison with the material published by Winkler and Schück. (Cf. Söderström, 1943, pp. 40—72.) The exception concerns Stolpe's *mattang*, of which it has not been possible to find any equivalent.

A comparison between Stolpe's, Krämer's and Winkler's charts of the same areas is not without interest (pp. 126—127).

Fig. 15 shows Stolpe's *meddo* of the area Jaluit—Ailinglablab (distance between the atolls about 80 miles) and Krämer's *meddo* of the area Ailinglablab—Namu (distance between the atolls about 40 miles).

Fig. 16 shows Stolpe's *rebbelib* and one of Winkler's *rebbelib* of the Marshall Archipelago. Of Stolpe's 16 *rebbelib*, 15 are basically of the same areas is not without interest (pp. 126—127).

The differences between Stolpe's, Krämer's and Winkler's charts are striking and cannot be explained simply by the fact that they were made by different navigators. In contrast to the charts of the other two, Stolpe's charts are so sparsely furnished with details relating to swell phenomena that it can be doubted whether they were of any particular value where navigational directions were concerned. Moreover, on examining his charts one has the impression that most of them are very carelessly constructed, and this cannot be explained merely by the fact that they have deteriorated during the long period they have been preserved in the museum. (This state of affairs, which emerges very clearly from an examination of the whole of Stolpe's material, cannot be illustrated here in sufficient detail owing to limitations of space.)

During his short visit to Jaluit Stolpe was able to secure no fewer than 27 charts. This is a surprisingly large number in view of the secrecy which usually surrounded these charts. It is hard to avoid altogether the conclusion that Stolpe merely succeeded in acquiring a number of "tourist souvenirs", manufactured in haste by a native navigator in order to satisfy an ethnographer on a flying visit. This may seem a harsh judgement, but there are plenty of indications that it is not altogether unjustified:

- (i) The defective construction and the poor execution of the charts.
- (ii) The large number of charts of the same area, made and owned by one person (at least 15 *rebbelib*). It would be very difficult to supply a satisfactory explanation of why so many copies of a

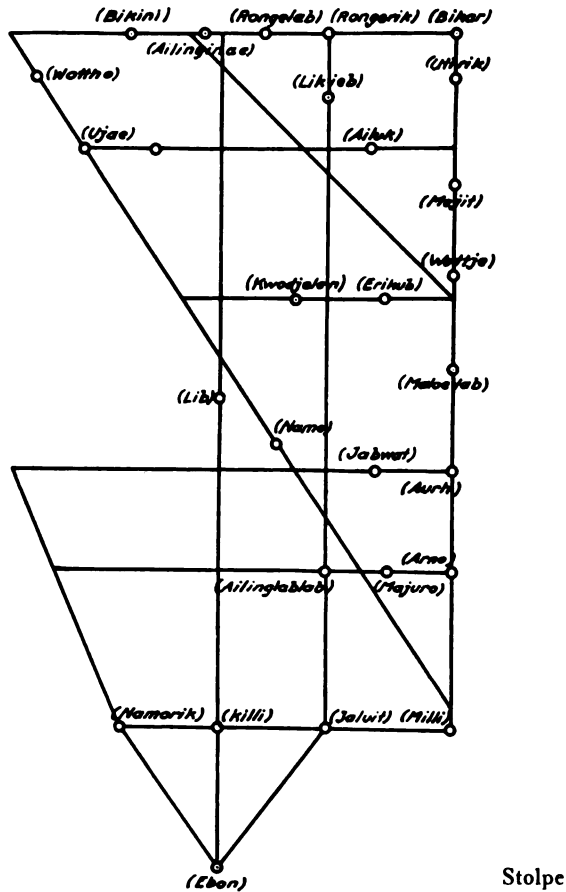
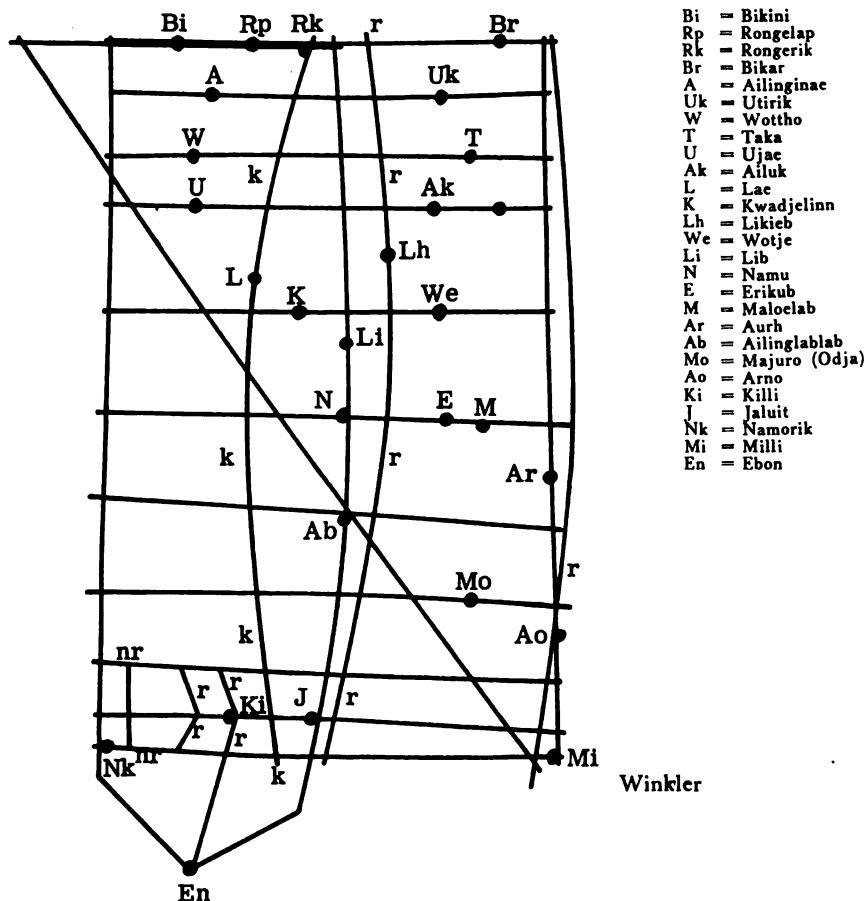


Fig. 16. Rebbelib (after Stolpe, 1884, and Winkler, 1898).

secret object were in the possession of one person. By comparison Winkler, who paid at least two long visits to the Marshall Islands, managed to acquire only five charts.

- (iii) The instructional chart (*mattang*) was declared useless by one of the acknowledged navigational experts on Jaluit.
- (iv) Before and after Stolpe's visit to Jaluit the existence of charts of a much higher quality had been demonstrated.

It appears that, with one exception, the material collected by Stolpe represents an inexplicable down-period in "cartographical" production. When Schück was collecting basic information for his analysis of the charts of the Marshall Islands he wrote to all the museums and institutions abroad whose collections were known to contain such charts, asking for details of these. Stolpe was one of the few who did not respond to this



request. The reason for this is not known, but it is possible that Stolpe realized that his material was not of a kind that could make any substantial contribution to Schück's investigation.

(3) Problems presented by the navigational charts

(a) *The distribution of the charts*

Most of the known charts seem to originate in the southern Ralik Group, primarily Jaluit, and only a few can be derived from the Ratak Group. It is uncertain whether cartographic representation of swell phenomena was known in all parts of the Marshall Islands. The chart

material described by Schück, and including Stolpe's collection, can be traced to Jaluit and Ebon (southern Ralik), Arno and Milli (southern Ratak). According to Davenport the principle underlying this form of navigation, "wave piloting" as he calls it, is still generally known by the navigators within an area stretching from Ebon to Jaluit and Wotje. It is unknown to him whether a similar kind of knowledge is also to be found in the northern part of the archipelago (1966).

There is no confirmation of similar charts having been used outside the Marshall Islands. Information suggesting they had been in existence in the Fiji Islands was convincingly refuted by Schück (1902, p. 33). In the journal *Pacific Discovery* (1952, vol. 5, p. 22) there is a photograph of a stick chart, said in the caption to emanate from the Gilbert Islands. However, the chart is a *rebbelib* of the Marshall Islands, and in appearance and construction closely resembles the type of *rebbelib* described by Winkler and Schück.

In all probability one is on safe ground in saying that the charts represented a system of navigation peculiar to the Marshall Islands. The need for and the requisite preconditions for the emergence of such a system as this also seem to be greater within this archipelago than within other island groups in the Pacific Ocean. The north-south orientation of the archipelago, athwart the trade wind and the equatorial currents, means that the swell phenomena have much the same characteristics in all regions, and can therefore provide the basis for a common navigational system. The short distances from which the atolls can be sighted and the unpredictable displacement owing to wind and strong variable ocean currents meant that orientation by means of heavenly bodies alone yielded extremely uncertain results, even over short distances. Thus there was an obvious need for additional aids to navigation, and the swell phenomena provided the opportunity for the creation of such aids.

(b) *The age of the charts*

Davenport has advanced the view that navigators in the Marshall Islands had developed their special navigational system, "wave piloting", before their first contact with the Europeans in the 16th century, and that they also knew how to express it graphically in the form of the stick charts (1964, p. 10). He came to this conclusion after a close study of the problems surrounding the stick charts, but he has since pointed out that it is only an assumption on his part and one which is not supported by any definitive data (1966).

The actual existence of the stick charts was not demonstrated until 1862 (Gulick), by which time the Marshall Islands had long been in

contact with Europeans. However, this cannot by any means be taken as indicating that the charts were developed at a late stage. The great secrecy with which they were always surrounded almost certainly meant that for a long period prior to this they had been kept hidden from the Europeans. Severe punishment awaited anyone who made any reference to the charts; "... the individual who first divulged the art to us, though the husband of a chief, was threatened with death" (Gulick, 1862; p. 304).

It is also remarkable that the charts, as has been mentioned above, seem to have had a relatively limited distribution within the archipelago. If they had been of real value in navigation one might have expected the opposite. It is possible that the reason was that the charts soon fell into disuse when the navigators made the acquaintance of European aids to navigation. In any case the apparently limited distribution cannot be taken as proof that they are of late origin. The distribution is no criterion of age.

(c) The origins of the charts

The question of whether the stick charts are an independent invention or the result of a stimulus diffusion, with the European sea charts providing the impulse for their construction, is a much disputed one. Similarly, doubts have been expressed as to whether the charts really could be a valuable navigational aid.

Winkler is hesitant on this point and formulated his views in this way:

"Meine anfänglichen Zweifeln gegenüber, ob überhaupt so vielerlei Anzeichen berücksichtigt worden seien, und meiner Ansicht, dass sehr wahrscheinlich nur die Hauptdünung, die Rilib, mit Zuhilfenahme der Gestirne die Grundlage für den einzuschlagenden Kurs gegeben habe, wurde, und wohl mit Recht, entgegengehalten, dass dann die verschiedenen Karten mit den vielen Linien und Bezeichnungen doch überhaupt nicht notwendig gewesen seien. Die Existenz dieser Karten, die feststehenden Bezeichnung der auf ihnen enthaltenen Linien beweist wohl jedenfalls, dass die durch diese Linien dargestellten Merkmale des Wassers beim Navigieren auch gebraucht sein müssen." (1898, p. 1437.)

Winkler's argument is hardly convincing.

It seems that a more realistic assessment of the problem could be based on the following facts:

(i) The principles underlying the swell phenomena, as these are expressed in the stick charts, were illustrated and explained to Winkler by the native navigators in 1898, long before the Europeans themselves

had theoretically formulated and explained these phenomena. This was not done until during the 20th century. (Davenport, 1966.)

(ii) The instructional chart (*mattang*) is a purely theoretical model of swell phenomena, and in it one cannot trace any influence from European cartography. The Europeans had no corresponding graphic representation of these phenomena, and could not have had any, since the underlying principles were not generally known.

(iii) The primary function of the *meddo*, unlike that of the sea chart, is to indicate the positions of the islands relative to observable swell phenomena, while the true distances and directions between the islands are only of secondary importance.

It therefore appears very likely that the principles of the navigational system were worked out and illustrated in the form of the *mattang* on a purely local basis without impulses from outside. Davenport's argument (i) seems to be wholly convincing. According to Davenport's assumption this navigational method, peculiar to the Marshall Islands, was developed by the Marshallese "in a specific response to some social motivation that we cannot pinpoint with surety (although one guess is the political advantage such information might have in their attempt to establish chiefdoms), and from there the experts developed means of explaining it to selected trainees" (1966).

As a result of the increasing contact with European navigators it is possible, however, that the *meddo* and the *rebbelib* underwent certain changes as time passed. This applies particularly to the *rebbelib*, on which the islands are given a relatively correct geographical position. It is, therefore, not unlikely that when constructing these the navigators took advantage of knowledge concerning the cartography of the archipelago, which they had acquired from European sea charts. (Cf. Winkler, 1898, p. 1428.)

As the stick charts are almost certainly an independent invention there can be no doubt that they have been a very useful aid to the navigator. A system as refined as that represented by the charts can hardly have been developed for its own sake, but rather in order to meet a real need.

4. *The voyage*

In the chapter dealing with navigation within the Carolines an account was given of the decisive influence exercised by the weather conditions over the selection of the time for sea voyages, and of how the direction and strength of the winds and the currents could be predetermined by

observations of the stars. What is said there is also generally valid for conditions within the Marshall Islands.

Weather forecasts were prepared by observing the position of certain stars (constellations) one hour after sunset and one hour before sunrise. Alongside this, observations of clouds played an important role in the assessment of the kind of weather to be expected in the immediate future. On the basis of information given from Arno-Jaluit Erdland has compiled a true "cloud atlas" (1914, pp. 71—75).

As a rule the sailing season began at the end of June or the beginning of July and lasted until the trade wind set in (about November). Apart from the fact that the strong winds at that time made sailing more hazardous, they also caused heavy seas, which made it more difficult to observe the various swell phenomena. Even during the sailing season a voyage was not embarked upon until the weather forecast predicted favourable weather and wind.

Long voyages were never undertaken by individual canoes, but only by several, sailing together. Such a flotilla usually contained some 25 to 30 canoes, but there could be as many as 70 to 80 (Winkler, 1898, p. 1435). As a rule canoes sailed in line abreast and 1 or 2 miles apart, which could greatly increase the chances of a safe landfall (Erdland, 1914, p. 61). The sail, made of plaited pandanus leaves, was easily affected by water, so during rainy weather it was lowered and covered to prevent damage. If the bad weather lasted for some time this resulted in the canoes' displacement being great and the position becoming uncertain.

The main principle of navigation by the swell required the canoe to follow the nodes, *bot*, which were formed between the east-west swell and between the north-south swell. When sailing between two neighbouring atolls the canoe followed the nodes coming from the first atoll until it reached the nodes from the other one. According to Winkler, a canoe which had sailed to one side of an *okar* could discover this through the fact that the easterly swell was easier to discern east of a north—south *okar*, while the westerly swell was easier to discern west of it. If the navigator had lost sight of his *okar* he had an opportunity, as he passed by an atoll, of observing one of the swell's refracted north or south arms coming from it and by following the arm reach the atoll in question (1898, p. 1437).

However, it was not only the diametrically opposed swells which could guide the navigator. From Winkler's account of the voyage between Jaluit and Mille (course 90°, about 80 miles) it is apparent that navigation was performed by means of the easterly swell (true direction east-north-east) and the southerly swell (true direction south-south-east).

These two swells intersect each other almost at right angles, something which it was claimed could very easily be observed. North of the course line the easterly swell was said to be the stronger, south of it the southerly one. The change in the direction of the easterly swell caused by Mille could be observed about 25 miles from that atoll and by holding a course between the refracted north and south arms of the swell (cf. Fig. 11) the canoe reached Mille (Winkler, 1898, p. 1438).

Although the nautical astronomy of the Marshall Islands received relatively little attention in ethnographical investigations, it is, as has already been mentioned, perfectly obvious that the heavenly bodies also played an important part in navigation, and that, as in Polynesia, the course was steered by horizon stars. As the swell phenomena could not be observed at night it is plausible to assume that then the navigators steered only by the stars. Davenport, however, states that it was possible for a skilful navigator to determine his position by noting the movements of the canoe alone and from this to deduce what kind of swells were acting on it (1964, p. 13). The credibility of this statement is confirmed to some extent by similar information from the Gilbert Islands (Grimble, 1957, p. 57). Navigation by reference to swell phenomena made great demands on the navigator's knowledge, experience, and powers of observation. He had to know the relative position of every island within the group, the sailing time between the islands, and also be able to interpret the characteristic swell phenomena found near the various islands, so that he could identify them when they were still out of sight and finally make a safe landfall.

Sea voyages of considerable extent were mainly undertaken within the Ralik group. The atolls and islands of that group all came under one chief and were for that reason in more or less regular contact with one another. Within the Ratak group, on the other hand, voyages between the atolls were rarer, since this island group was divided into several chiefdoms between which there was a permanent state of war. Peaceful relations were not maintained between the two island groups and such contacts as were made were of a warlike nature. The fact that seafaring was on a limited scale also meant that only a few navigators knew the atolls of both the Ralik and the Ratak island groups. No sea voyages were voluntarily undertaken to areas outside their own archipelago, and when voyaging within the island groups the canoes sailed in stages via the nearest atoll or island. (Winkler, 1898, p. 1433; Erdland, 1914, pp. 59—60.)

It is not known whether sea voyages over distances greater than those quoted here were accomplished in former days.

As regards islands outside their own archipelago the navigators of

the Marshall Islands knew the positions of the eastern Carolines and the Gilbert Islands. Knowledge concerning these had probably been acquired already in pre-European times owing to canoes being blown off course. This is suggested by the fact that certain elements in the culture of the Marshall Islands may possibly derive from those areas (Krämer & Nevermann, 1938, p. 217).

The Gilbert Islands

1. *General*

The Gilbert Islands consist of about 16 low-lying atolls and islands which extend for about 350 miles in a NNW-SSE direction. The maximum distance between neighbouring atolls is about 120 miles. The mean latitude of the archipelago coincides with the equator. The minimum distances to the Marshall Islands to the north and the Ellice Islands to the south are about 200 miles. Like the Marshall Islands, the Gilbert Islands lie athwart the trade wind and the equatorial currents, which, however, are not as strong as within the archipelago to the north.

Thanks to the accounts supplied by the late Sir Arthur Grimble, a colonial official who became Governor of the Gilbert and Ellice Islands, our knowledge of Gilbertese astronomy is unusually good (1931, pp. 197—224). On the other hand we do not know much about the way in which the astronomical knowledge was applied in navigation.

Grimble collected his material on the northernmost atoll, Butaritari. Some portions of this are peculiar to this atoll and Grimble was unable to find anything corresponding to it in the rest of the archipelago. It cannot be maintained with certainty, therefore, that the brief account of Gilbertese astronomy given here is valid for all the Gilbert Islands.

2. *The celestial sphere*

The night sky was regarded as the vast roof of a house running north and south, the observer being by its central pillar. The whole of the astronomical terminology goes back to this concept. The celestial sphere was called, literally, “the roof of voyaging” and the eastern and western horizons were called “the roof-plate of the east” and “the roof-plate of the west”, respectively. (Cf. Fig. 17, p. 136.)

The ridge-pole of the roof formed the celestial meridian. The roof was supported by sloping rafters, three on the eastern side and three on the western side, one end resting on the roof-plate, the horizon, and the other end on the ridge-pole, the meridian.

The three pairs of rafters represented the paths of the Pleiades and the stars Rigel and Antares.

The northern pair of rafters met on the ridge-pole where the Pleiades,

declination 24° N, crossed the meridian, while the southern pair had their apex where Antares, declination 26° S, culminated.

Since the mean latitude of the Gilbert Islands is about 0° the celestial equator passes through its zenith, and the declination of a star, when on the meridian, is at the same time its angular distance from the zenith (zenith distance).

The middle pair of rafters, which represented the path of the star Rigel, is said to have formed the Gilbertese celestial equator. As Rigel's declination is 8° S this equator lay the same number of degrees south of our own, and also 8° south of the Gilbertese zenith.

On each side of the roof, between the horizon and the meridian and parallel to them, the astronomer imagined there were three purlins (parallels of altitude) across the rafters, an equal distance apart. The height of the heavenly bodies above the horizon was indicated by reference to the purlins, while the sloping rafters made possible a rough estimate of the declination. To allow a more accurate determination of altitude each of the four zones formed by the purlins was divided in two parts. Each new zone thus formed covered an angular distance of about 11° .

On the equator the stars seem to move at right angles to the horizon. The Gilbertese celestial sphere is thus roughly the equivalent of what is called "the right sphere". Its coordinates were: the celestial meridian; the horizon; three parallels of declination (one 24° north of the zenith, two of them 8° and 26° respectively south of it); seven parallels of altitude, 11° apart.

Makemson considers it remarkable that Rigel, at 8° south of the zenith of the Gilbert Islands, has been chosen to represent the central point in the system and its path the equivalent of our celestial equator. The explanation for this, she says, is that the astronomical system originated, not in the Gilbert Islands, but in an area 8° — 10° south of the equator, where Rigel passes through the zenith of the observer. Makemson is of opinion that this proves a former connection with the early settlers in New Zealand, for whom *Puanga* (Rigel) was synonymous with zenith. She seems by this to suggest two specific migrations starting from a common homeland, possibly Java or southern New Guinea (lat. 8° S— 10° S). (1941, p. 107.)

Owing to the precession of the earth's axis, however, the declinations of the stars is continuously changing. In order to be able to determine the latitude of a migration centre with the help of Rigel's declination, we must therefore know when the migration started, and from this work out the declination Rigel had at that time. If a latitude determination of this sort is to be of any value, it must be assumed that a clearly defined zenith point was included in the astronomical system.

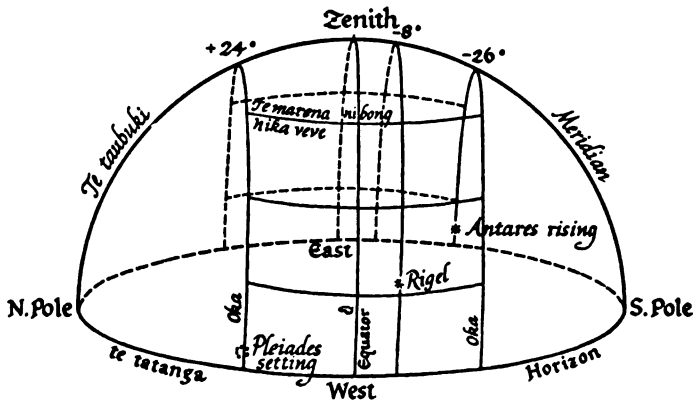
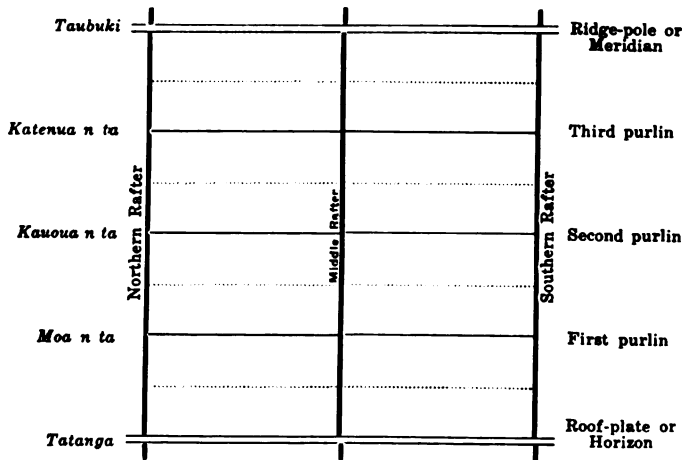


Fig. 17. The Gilbertese celestial sphere (after Grimble, 1931, and Makemson, 1941).

This question has already been discussed in connection with Polynesian astronomy. The point made there was that it is not possible to draw any conclusions of the kind mentioned above by comparing a "primitive" system of astronomy with our own strictly mathematical one, constructed so as to be universally valid. Unlike our own astronomers, the Gilbertese astronomer had no use for an exactly defined zenith or a celestial equator. His system required only a star or a constellation whose path divided the celestial sphere approximately into two halves. Whether this star culminated a few degrees north or south of his zenith made no difference. Similarly, it was a matter of no importance for the navigator.

Makemson's latitude calculation is therefore based on two mistaken assumptions: Rigel's present declination and the concept of the zenith. Consequently her conclusions, too, cannot be accepted.

3. *The sun and its motion*

The sun's apparent motion to the north and south during the year was determined by observing which constellation it entered at sunrise or sunset. The observations were made at 10-day intervals from a stone platform which gave an unrestricted view of the horizon. The sun was said to have reached a new "station" every tenth day. There were 36 stations (the four cardinal points plus 16 points on the western horizon and 16 on the eastern horizon). Each station had a name and its position on the horizon was known to the navigator. Owing to his knowledge of the direction to the sun at sunrise or sunset the navigator was thus able to check his course at these times of day. Certain of the stations were said to have been named after islands that could be reached by steering towards the points on the horizon bearing their names. On checking this information, however, one finds that in the majority of cases there are no islands corresponding to these points, merely the empty sea. (Grimble has supplied a sketch of the "sun compass" in which the names of the stations are apparently evenly distributed all round the horizon. In reality such a compass can cover only the portions of the horizon where the sun rises and sets, that is to say, an arc of about 23.5° on each side of the east-west axis at the eastern and western horizon respectively.)

Grimble, who has given an interpretation of the sun's station names, considers they are very old, dating back to a time when the language of the Gilbert Islands had not yet reached its present form. He finds support for this view in the fact that in the names of the stations there are words which, while common enough in other Polynesian languages, are no longer used in modern Gilbertese.

One or two of the station names are of special interest:

Te-take: the tropic bird. Could also imply a now forgotten reference to the Marquesas Islands, whose inhabitants call themselves *te-take*.

Makaiao (Maiawa): Said to be a land far to the east reached by seafarers in ancient times. The tradition states that it is not an island but a vast country with high mountains and rivers, which lies further east than all the islands. Grimble asks whether this may not be a folk-memory of voyages to the South American continent, previously undertaken by Gilbertese, though not necessarily from their present area.

Makemson is more categorical and considers this to be a clear reference to Central America; the similarity between Maia in Maiawa and Maya may be more than a coincidence (1941, p. 106). The conclusion seems over-hasty. It is not supported by any semantic investigation. The apparent external resemblance between the words tells us nothing about any com-

mon background of meaning or about any relationship between them. It should not be overlooked, either, that seafarers from the Gilbert Islands might have visited the American continent on board European ships and their experiences may have been preserved in the form of the tradition.

The lack of agreement between the directions indicated by the station names and the geographical surroundings, as well as the fact that certain of these names are possibly of foreign origin, seems to suggest that this sun compass was not developed locally, but was brought in already perfected by immigrants to the Gilbert Islands.

However, it has not proved possible to demonstrate any corresponding method of indicating direction by reference to the sun's annual motion within either Micronesia or Polynesia.

The solstices and the autumnal equinox were determined by observing the Pleiades, while the vernal equinox was determined by observing Antares. The star's (constellation's) height above the horizon on these occasions was given in relation to the three parallels of altitude (the purlins).

4. Navigation stones

On Arorae, the most southerly of the Gilbert Islands, there is a group of eight or nine stones which, according to the information collected by Hilder, formerly guided navigators bound for four islands to the northwest at distances of between 50 and 85 miles. The directions indicated by the stones deviated on average about 5° from the true courses. Hilder regards this deviation as the one required in order to compensate for leeway and current. The stones cannot have served as leading marks, as they are so low that they are soon lost to sight from a canoe. Hilder considers it more probable that, before departure, suitable guiding stars for the voyage concerned were selected by means of the stones, that is to say, stars which set in the direction indicated by the leading line. (1959, pp. 90—97.)

5. The voyage

The sailing season within the Gilbert Islands lasted from the culmination of the Pleiades after sunset to the culmination of Antares at the same time of day, in other words from about the end of February or the beginning of March until September. As was the case within other parts of Micronesia the navigator prepared weather forecasts by observing the positions of the stars in the night sky. It was also believed that advance

warning of a deterioration in local weather conditions, which might spell danger to a voyage that was imminent, could be obtained by watching the behaviour of certain animals.

There is an almost complete absence of information about the practice of navigation, though it appears from Grimble's account of a canoe voyage among the islands that the course was maintained by means of horizon stars during the night and the direction of the swell during the day.

Polaris, which was a sure indicator of north within the rest of Micronesia, is not visible from the Gilbert Islands. It is not known whether the navigators knew how to determine north and south with the help of the Southern Cross, though it seems probable that they did.

Owing to our knowledge of the well-developed Gilbertese system of astronomy we know that the heavenly bodies were observed at the transit. Thus it is probable that true north-south was determined when the sun was on the meridian and that the canoe's course was corrected with reference to this. The sun compass also made possible a reasonable accurate check of the course at sunrise and sunset.

The details concerning Gilbertese navigation emanate from the northernmost and the southernmost islands in the archipelago. Corresponding information from the rest of the island world has not been forthcoming. For this reason it is not possible to draw, with certainty, any general conclusions about the navigational methods within the Gilbert Islands. If, as seems likely, regular contacts were maintained at one time between the various atolls of the island group, then it seems probable that the same astronomical system was employed throughout the archipelago. On the other hand, no equivalent of the navigation stones on Arorae has been reported from any other island in the Gilbert group, and so it would appear that these stones should be regarded as peculiar to this island as far as the archipelago is concerned. As previously mentioned, the existence of landmarks arranged in the shape of leading lines or marks to facilitate nautical-astronomical observations has also been demonstrated within Polynesia.

Special aids in navigation

In one of the passages dealing with Polynesia we discussed the natural aids to navigation in the shape of cloud formations, reflections, etc., which indicated to the voyager the presence of and the direction to land, and thus facilitated a landfall. What is said there also applies in general in respect of Micronesia. It is important, however, to bear in mind that, in contrast to what is the case within many island groups in Polynesia, the islands and atolls in the Micronesian archipelagoes are, almost without exception, very low-lying indeed and cannot be sighted from distances in excess of about 11 miles. This circumstance makes great demands on the skill of the navigator and limits the distances over which voyages can be undertaken with a fair chance of a successful landfall. Grimbale has supplied a brief but clear account from the Gilbert Islands of this non-astronomical type of navigation, which can be regarded as valid for the whole of Micronesia:

"Having set out on his voyage, and dropped the land the navigator will keep his eye on the birds. If he loses sight of these he knows that no land is near. But if, after a long voyage, he meets a flock of gulls, which mount high in the air and cast about to different points of the compass, he will steer in the direction they ultimately take, for that way lies terra firma. Another sign of land for which he watches is its 'loom' upon the horizon. This I have many times seen myself; it is quite unmistakable. The white sand and still lagoon of an atoll reflect the tropical sun-glare upwards, so that a pale, shimmering column is shot into the air over the island, whose presence is thus betrayed at a great distance. The clouds also have a tale to tell. When a mass of cumulus towers over an island, some draught, caused probably by the refraction of heat, bends over the pinnacles of the cloud, so that it dips towards earth. Twice, while at sea, this phenomenon has been pointed out to me by a native, and in both cases it proved a true compass.

"When visited by a squall of rain between lands, or when travelling by night, with only a sense of direction to guide him, the sailor observes the waves. If these suddenly change in direction he knows that land is near; especially sure is he, when he passes from a beam-sea into a swell that lifts first the stem and then the stern of his craft." (1924, p. 128.)

The Gilbertese voyager feared to get too far to leeward of his islands when the south-east trade was blowing. It was believed that beyond

the western edge of the world there was a deep abyss into which the canoe would be drawn if it failed to beat back to its own islands.

"So as not to stray outside the limits—especially the westward limit—of safety when they navigated beyond sight of land, generations of fishermen and voyagers built up out of their experience a system of *betia*, or sea-marks, by which, if only a man knew enough of them, he could be sure of his position in relation to any island of the Gilbert group. These signposts in mid-ocean might be shoals of fish, flocks of birds, masses of floating weed, or merely the way certain fish, or birds, or weeds behaved. They could be shapes of waves, or their size, or direction, or frequencies; they could be lines of driftwood, or shining streaks on the face of the waters, or conditions of atmosphere, like high or low visibility, or even the smell of the air, ranging from land scents to *te boi-n-anti*, the 'stink-of-ghosts', that told you how near you were drifting to the western point of no return . . .

"The point of no return in the western seas was a *betia* called the Fishtrap of Kabaki, a scattered line of leaves and driftwood, said to stretch in the navigating season from the ghost lands in the far North-West south-eastwards to the latitude of Samoa." (1957, p. 51.)

There is a suggestion in certain sailing directions from Ifaluk that similar "seamarks" may have been of importance for navigation within the Carolines as well. One of these directions, relating to a voyage to Woleai, contains information about the presence of certain species of birds and fish in addition to the astronomical and terrestrial details. (Burrows & Spiro, 1957, p. 99.)

Within the Marshall Islands the atolls were associated with a supernatural being, *Ākejab*. *Ākejab*'s offspring were birds, fish or drifting objects which could be observed within a certain distance and on a certain side of the atoll. As these were relatively stationary they could serve as orientation marks for the navigator and indicate the position of the atoll to him. Erdland has reported such seamarks for thirteen atolls. (1914, pp. 347—362.)

This kind of navigational aid is not peculiar to Micronesian navigation, however. Similar information can be found in Polynesian voyaging traditions.

As far as "seamarks" of the kind mentioned above are concerned, the information contained in the sailing directions may appear fantastic and worthless from a navigational point of view, at least in the form it now assumes. Nevertheless one cannot exclude the possibility that this might very well deal with reminiscences of a long-forgotten knowledge of local currents and of characteristic behaviour found among the local fauna, which at one time could have been of real importance when making landfall.

Navigators and navigation schools

The astronomy which developed within cultures based on farming was mainly intended to determine the times for activities and ceremonies that were connected with agriculture, by observing the positions of the heavenly bodies. Accordingly, the knowledge required in this respect was often the preserve of religious specialists.

On the other hand, within Micronesia it was the navigational requirements which essentially determined the development of astronomy. Nautical-astronomical knowledge was an absolute necessity if long voyages were to be undertaken and communications maintained between the islands. But this knowledge had to be supplemented by a thorough knowledge of meteorological and hydrographic conditions, so that auspicious times for sea voyages could be determined and the displacement of the canoe due to leeway and current predicted.

As a rule it was only the professional navigators who possessed nautical knowledge. This was regarded as a trade secret, as private incorporeal property. As such it was handed down from father to son—in the Marshall Islands from father to daughter as well—but in matrilineal societies it might also be transferred from maternal uncle to sister's son. The knowledge was not the joint property of the family, but was known only to one or two individuals. In the Carolines, however, a person who could not acquire nautical knowledge through inheritance could buy it at a high price if he could find someone willing to sell.

The navigators were held in high esteem, and had a status next to the chief, but this standing did not entitle them to any tangible advantages or any precedence except on board a sailing canoe. Although the navigators kept their nautical knowledge strictly secret from outsiders, there was within the Carolines a free exchange of experiences between acknowledged professional colleagues, even if they came from different islands. (Burrows & Spiro, 1957, pp. 87—88, 122.)

In Micronesia navigation was taught at special schools, where the instructional period varied in length. In the Carolines it lasted between one and two months (Damm & Sarfert, 1935, p. 83—84), in the Marshall Islands between six and twelve months (Erdland, 1914, p. 92; Krämer, 1938, pp. 215—216). The schooling ended with the pupil acting as navigator on a training cruise; only when he had successfully proved his

knowledge in this way was he accepted as a qualified navigator and allowed to command his own canoe. .

In the Gilbert Islands astronomy was studied indoors. The framework of the dwelling represented the coordinates of the celestial sphere, within which the positions of the various constellations relative to each other and Rigel were learned. Before the pupil was allowed to identify stars in the night sky he had to have a thorough mastery of this "star chart", and also know by heart a long list of guiding stars to many islands in the archipelago.

One method of making it easier to memorize the sailing directions was to "weave a tale about them", in which the stars figured as persons, animals or objects which had been seen during the voyage. The best known of the folk-tales were often adapted to this purpose. (Grimble, 1924, pp. 133—134.)

As already mentioned, the navigational charts of the same area of the Marshall Islands are not always identical. These divergences are ascribed to the different constructional methods of different schools. In contrast to the situation in the Carolines there was no exchange of experiences between navigators belonging to different schools. Instead they tried to keep their charts, and the nautical experiences which formed the basis for their construction, strictly secret from one another. It is possible that this was due partly to professional jealousy among the navigators, and partly to the rivalry between the chiefs to whom the navigators owed allegiance.

Astronomy and time measurement

Astronomical observations form the basis of time measurement and the division of the year into periods within the whole of Micronesia. There is no uniform system for the various archipelagoes, however, and local variations are to be found even within individual archipelagoes.

(a) The year and its seasons

The original, and at the same time the simplest way of determining an annual cycle is based on observations of seasonal variations in nature, the times at which plants bear fruit, flower and wither, the arrival and departure of migrating birds, the regular changes in the trade winds and the monsoons, etc.

For cultures which had a subsistence economy primarily based on agriculture it was natural to allow activities and events which bore some relationship to this to form the basis for a division of the year into different periods.

Within certain regions of Micronesia the bread fruit is the most important item of food and its seasonal variations forms the basis for a "feastday calendar" (Truk) and also for a division of the year into two periods (Goodenough, 1953, p. 25). During one of the seasons breadfruit is plentiful, during the other it is less so. The former season covers the period from about June to November/December, the latter the remaining part of the year, when the trade wind also prevails. The division of the year into two seasons is general practically throughout Micronesia, though it is only within certain parts of the Carolines that one of them is connected with breadfruit. The two seasons are called *rak*, *rag* or *ras* and as a rule are named after the phenomena that are most characteristic of them. On Yap and Truk they are named after the trade wind and rain/breadfruit respectively, while on Ifaluk they are named after the trade wind/fishing and breadfruit respectively.

The trade-wind period commences at about the same time as the Pleiades first appear on the horizon after sunset (end of November or early December); the ripening of the breadfruit coincides broadly speaking with the rising of Antares at the same hour (early June). These heavenly bodies have therefore been related to two of the most important events

the community recognizes during the year, and the appearance of the stars above the horizon is the sign of the beginning and the end of the seasons.

Over wide areas of Micronesia the new year was ushered in when the Pleiades or Antares appeared above the horizon in the evening (December and June respectively), and the time that elapsed until the star again rose above the horizon after sunset constituted the Micronesian year. (The information concerning the Antares year in the Carolines is derived from Goodenough, 1953, p. 28, but it has not been possible to verify it.)

In the Gilbert Islands the year is regulated by observing both the Pleiades and Antares. The year, and thus one of the seasons, commences when the Pleiades rise at dusk (early December). This season ends when Antares appears above the horizon in the early evening sky (early June). The second season then begins and lasts until the Pleiades are once again visible on the horizon after sunset. (Grimble, 1931, p. 200.)

Within the south-western Carolines (Sonsorol, Pur, Merir) the year is reckoned on a somewhat different basis. It is named after the star Altair, which indicates the cardinal points east and west on the sidereal compass. The new year is said to begin when the sun rises at the point on the horizon which the compass assigns to Altair. (Eilers, 1935, pp. 82, 243, 360.) (Apart from the solstices, the sun passes the same point on the horizon twice a year, once when moving north and once when moving south.)

Sunrise at the compass point Altair occurs at about the beginning of September and again during the first half of April. Eilers gives the first of these times as the new year, Goodenough the second one. This incompatibility stems from the fact that definite information is lacking about the direction of the sun's apparent motion in the ecliptic at the moment of observation.

(b) Calendar

The conspicuous change in the phases of the moon has given rise to a lunar calendar in the Carolines, in which every month has thirty days (duration from new moon to new moon 29.5 days). The months have been named after constellations.

Alongside this lunar calendar there is another calendar, according to which the year is divided into a number of periods of unequal length based on the position of various constellations. (Goodenough has called these periods "sidereal months". This is not quite correct, however. The sidereal month is in fact the duration of one complete revolution of the

moon about the earth, relative to the stars; about 27.5 days.) Each period is named after its constellation, which is placed in relation to the weather and wind prevailing during the period. The purpose of this division of the year is mainly to furnish the navigator with an almanack, which tells him the times of the year when it is appropriate or inappropriate to set out on sea voyages.

In general the number of lunar months varies between twelve and thirteen, while the number of navigational periods can be as great as eighteen.

The lunar months and the navigational periods are usually named after constellations which rise at dawn or set at dusk.

In the central Carolines lunar months and navigational periods often have the same denomination, *maram* (moon). It can therefore be said that there are two calendars in use here, one consisting of lunar months and the other of navigational months.

The coexistence in certain areas of two calendars with different kinds of months, all named after stars or constellations, has made it difficult to give a clear outline of the calendar system. This is particularly so in view of the fact that the longer navigational calendar seems to have been abridged with the intention of bringing it into closer agreement with the lunar calendar, a process which still appears to be going on. (Goode-nough, 1953, p. 28.)

Deviations from the principles for time measurement referred to here are to be found. As mentioned previously, the months of Yap, for example, thus take their names from certain social activities and not from constellations.

As far as the Marshall Islands are concerned the necessary basis is lacking for an account of its calendar.

In the Gilbert Islands the year was divided into two seasons named after the Pleiades and Antares. Each of the seasons was subdivided into eight periods, whose durations were determined by observing the altitude of the Pleiades or Antares one hour after sunset. Apart from three cases, the names of the periods alluded to conditions which affected navigation. The phases of the moon were observed but did not give rise to a lunar calendar equivalent to that within the Carolines. The Gilbert Islands calendar was therefore constructed solely to satisfy navigational requirements.

Astronomy and navigation within Micronesia

Summary

It seems appropriate to make a summarized classification of the astronomy and navigational methods of the Micronesian archipelagoes on the following basis:

- (a) *The nautical system.* This can be based on
 - (i) direction given with reference to a fixed system, based on the bearing to a definite number of rising and setting stars, differing in declinations and right ascensions: sidereal compass
 - (ii) direction given with reference to the bearing to a definite number of rising and setting stars, with the same declination but differing right ascensions: horizon stars
- (b) *Special navigational aids*
- (c) *Year and calendar.* These can be regulated by
 - (i) the rising or setting of heavenly bodies
 - (ii) the altitude of heavenly bodies

Taking into account these factors a summary of known data gives the following result:

<i>The Carolines</i>	(a) sidereal compass
	(b) —
	(c) year: Pleiades year or Antares year calendar: lunar months and navigational months, often named after and determined by means of rising stars
<i>The Marshall Islands</i>	(a) horizon stars
	(b) navigational charts
	(c) ?
<i>The Gilbert Islands</i>	(a) horizon stars, sun compass
	(b) navigation stones
	(c) year: Pleiades year. Seasonal division by means of the Pleiades and Antares calendar: navigational periods, determined by meas- uring the altitude of the Pleiades and Antares. Names mainly referring to navigational conditions.

It is probable that true north-south could be determined within all three archipelagoes by observing the sun, Polaris (except in the Gilbert Islands) and the Southern Cross.

The Marshall Islands and the Gilbert Islands form uniform language areas of their own, each possessing its special navigational methods. Within the Carolines, on the other hand, the situation is more complicated. With the exception of Palau, Yap, Ngulu in the west and the Polynesian outliers Nukuoro and Kapingamarangi, as well as Ponape with adjacent islands in the east, the Carolines form a single language area, the Central Carolinian. Within this there is a common system of astronomical navigation and a more or less common calendar. The astronomical navigational methods have spread from there to the western Carolines, which have incorporated them in their culture, while the original calendar, differing from that of the central Carolines, has been retained on Yap but not on Ngulu.

Available data from the eastern Carolines are meagre. From these it appears, however, that Kapingamarangi has the same astronomical navigational method as the central Carolines and that Nukuoro has probably borrowed its calendar from the same quarter. One might therefore be allowed to draw the conclusion that from a nautical astronomical point of view the Carolines form an area with a common navigational method, which is also shared by cultures not forming part of the Central Carolinian language area.

Since, from the nautical and astronomical points of view, the three Micronesian archipelagoes form separate units, which are, moreover, differentiated by language boundaries, it is not possible to speak of Micronesian astronomy and navigation, but only of Carolinian, Marshallese and Gilbertese astronomy and navigation.

Common to the astronomy and nautical astronomy of the Micronesian archipelagoes are both a time reckoning based on observation of the stars and a course setting by means of rising and setting stars. It therefore seems probable that the original settlers in Micronesia brought this basic knowledge, and that in the course of the centuries this has been modified and developed in various directions in order to satisfy the requirements made primarily on nautical knowledge within the individual archipelagoes. This accounts for the emergence of the nautical systems mentioned above, the Carolinian, characterized by the sidereal compass, the Marshallese, characterized by horizon stars and navigational charts, and the Gilbertese, characterized by horizon stars, the sun compass and, as a special case, navigation stones.

Regular communications between the islands and atolls within the

individual archipelagoes conduced to the creation within each of them of a uniform astronomy and navigational method. The language, and as a result the astronomical nomenclature, changed from its original form and underwent an independent development within the various areas. This has resulted in there being only a few cognate words in this nomenclature within the Carolines, the Marshall Islands and the Gilbert Islands.

The fact that, from the linguistic as well as the astronomical and nautical points of view, the archipelagoes of Micronesia form relatively clearly defined areas, seems to suggest that any contacts between them have been on a modest scale only. The distance from the Gilbert Islands to the Marshall Islands and from the Marshall Islands to the Carolines is about 200 miles in each case. To be sure, these distances are considerable but they need not necessarily have put any insurmountable obstacles in the way of occasional, if not intensive, contacts between the archipelagoes, provided their relative positions were known. That this was the case, and that this knowledge was to a great extent supplied by voyagers blown off course, seems to be confirmed by the details given in this respect in the literature. Of course, a more or less permanent enmity between the inhabitants of the various archipelagoes, together with inaccurate methods of navigation, may have served to render contacts more difficult or even impossible.

The navigational methods employed on voyages outside as well as inside the island groups were based on dead reckoning and on landfall made through observation of swell phenomena, cloud formations, etc.

Long ocean voyages over areas with variable currents predominating could therefore appear hazardous with the methods available. The ability to determine latitude by observing Polaris, for example, would have greatly increased the reliability of the navigation and would have afforded greater possibilities of making a successful landfall. However, there is an almost complete absence of information that might support the view that the latitude could be determined by the Micronesian navigator.

The navigational methods were instead directed towards meeting the requirements presented during voyages within the archipelagoes.

Thus, the Carolinian sidereal compass was adapted to voyages within the Carolines, the islands and atolls of which were placed in relation to the points of the compass. The navigational charts of the Marshall Islands were constructed in order to illustrate swell phenomena peculiar to this island group. The Gilbert Islands sun compass was valid only at the latitude of these islands and Arorae's navigation stones were of value only to that island.

The principles underlying the various methods were generally valid, however, and to some extent applicable within all the archipelagoes.

The sidereal compass was superior to the horizon star method, and the navigational charts represented a refined method of wave piloting. The sidereal compass could quite easily have been adapted to the latitude and geographical surroundings of the Marshall Islands and the Gilbert Islands. The navigational charts, on the other hand, had been developed in response to the special conditions obtaining in the Marshall Islands, occasioned by the archipelago's extension right across the equatorial currents and the trade wind. The conditions for and the need of such an advanced method were not present in the Carolines, as its main orientation is east-west. However, it seems that the same underlying principles could with advantage have been applied there. Within the Gilbert Islands observations of currents and swell was an important element in navigation, but we do not know how much knowledge of these was possessed by the navigators, or how they put it into practice. At any rate it seems likely that the Marshallese method of wave piloting would have been applicable within the Gilbert Islands as well, even if the need for it was probably not so pronounced as it was within the northern archipelago.

Thus it seems probable that the different methods might have offered certain nautical advantages even within archipelagoes other than those where they developed. But there was no diffusion of these methods. Various explanations may be sought for this, but it is plausible to assume that the contacts between the archipelagoes were so sporadic that the opportunities for a diffusion were not present. The great secrecy which surrounded nautical knowledge is also likely to have been an important factor in preventing it from being imparted to anyone outside a certain group, especially if the individual concerned belonged to a foreign and possibly hostile tribe. However, a discussion of this special diffusion problem falls outside the scope of this essay, and it is, moreover, extremely doubtful whether it can now be solved.

It has been mentioned previously that it seems probable that the various Micronesian navigational methods have developed from a common basis shared by the original settlers in Micronesia. It has not been possible to delineate the migration routes with certainty and opinions concerning them differ. Through lexico-statistical methods Dyen has advanced a hypothesis about the Malayo-Polynesian migrations (Murdock, 1964, pp. 117—126). He considers that they originated in the vicinity of the New Hebrides and the Banks Islands. Among the migrations from this region there was one that went north-eastwards to Polynesia, possibly by way of Fiji, while a westward migration of people speaking the Carolinian languages took place through Micronesia to Formosa. Dyen further suggests that a certain connection can be traced between the northern Celebes, the Chamorros in the Marianas and Palau in the western

Carolines. In this connection it would seem to be of some interest to find out whether the nautical astronomy can make any contribution to the theories concerning the migrations.

The basic principles of astronomy and nautical astronomy within Polynesia and Micronesia are the same and the navigational methods are, with certain exceptions, so similar that one is justified in assuming that they were derived from a common source. The fact that the star Rigel was of great significance in the astronomy of the Maori and the Gilbertese has, as already noted, led Makemson to the conclusion that these peoples had migrated from the same cradle, at a latitude of about 8° S, approximately equivalent to the southern coast of New Guinea and Java. This corresponds fairly well with Dyen's opinion about the homeland of the Polynesians and Micronesians. However, it has already been shown that the premises on which Makemson based her argument are not acceptable and that therefore her conclusions are not relevant.

The discrepancies which exist in the monthly calendar on Sonsorol (the western Carolines) has induced Eilers to try to deduce from this the date for the origin of the calendar (Eilers, 1935, p. 87). The months are named after certain stars or constellations (compass points) in which the sun rises during its annual motion in the ecliptic. Thus, the month when the sun rises in Altair (the compass point) ought to be called Altair. It so happens, however, that the particular month when the sun rises in Altair does not have this name, but is called Antares. Eilers considers that it is possible to determine the age of the calendar by calculating how long ago it was since the sun rose in Antares at this time of the year. Goodenough, however, is of opinion that this apparent discrepancy might be resolved if the inhabitants of Sonsorol, as is the case on the neighbouring Ngulu, kept a lunar calendar and a navigational calendar, both with the same month names. (This seems to imply that Eilers has confused the nautical months with the lunar months and that her statement is not correct.) Otherwise Goodenough considers that the explanation must be found in the fact that the nautical months begin at times other than the helical risings of the constellations for which they are named (1953, p. 28).

It therefore seems impossible on a nautical-astronomical basis alone to draw any conclusions concerning the date of the migrations or the area from which they originated.

In the account of astronomy and nautical astronomy within the western Carolines it was demonstrated that the calendar on Yap was quite different from that in use on the other islands of the archipelago and that it was instead related to that of the Chamorros in the Marianas; it was also shown that the nautical astronomy on Yap (the star compass) had probably been

borrowed in its finally developed form from the central Carolines. The special position of the western Carolines in relation to the remainder of the archipelago seems, therefore, to support Dyen's theory of a link between the northern Celebes, Palau and the Marianas. The westward spread of nautical astronomical knowledge shown to have taken place through the Carolines might, if one bears in mind the close relationship between the Polynesian and Micronesian methods of navigation, also be interpreted as an indication that the migrations went from Polynesia to Micronesia.

The possible development of Micronesian nautical astronomy outlined here does not admit of a diffusion from Indonesia. Goodenough has observed that any such diffusion is most unlikely to have taken place in recent times. (This view is shared by, among others, Heyerdahl, who is of opinion that Indonesian impulses never reached further than to Yap and Palau. 1952, p. 54.) If any diffusion from the west occurred at all Goodenough considers that it must have been at a very early stage, at the same time or almost at the same time as the first settlers reached the Carolines (1953, p. 41). It is highly unlikely that it will be possible to demonstrate such an early diffusion, since the original Indonesian astronomy appears to be completely submerged beneath Hindu-Arabian conceptions and nomenclature.

SUMMING UP

"If you would find an expert on stars, you must ask for a *tiaborau* or navigator. This fact affords a correct measure of the significance of astronomy to the native; he regards it as mere adjunct (though an important one) to the larger science of navigation. Herein lies the secret of the difficulty to-day of getting any reliable information about native astronomy; for navigation has been a waning science since the advent of European ships and easy travelling, while the prohibition laid by the local administration upon long and risky inter-island voyages by canoe has conspired to hasten the decay. Of the 30,000 inhabitants of the sixteen Gilbert Islands, there are not twenty living to-day who can speak with knowledge about stars. Further, those who have the knowledge are often most unwilling to impart it, for of all the secrets treasured by the native, those connected with navigation are still perhaps the most jealously prized and guarded."

With these words Grimble opens his study of astronomy in the Gilbert Islands, published in 1931. The picture he presents here of the standing of astronomy within the culture, and the gradual disappearance of astronomical knowledge as sea voyaging declined, is probably relevant to the whole of Micronesia and in some respects to Polynesia as well. Within the latter region, however, much more of the factual nautical-astronomical knowledge had already fallen into disuse and been lost by that time. This can be viewed as a result of the longer and more intensive contact Polynesia had had with European culture.

The material available for a reconstruction of the astronomy and the navigational methods stems partly from descriptions of journeys, reports by missionaries and administrators from the late 18th century onwards, and partly from ethnographical studies from the end of the 19th and the beginning of the 20th century.

Traditions and myths are abundant, primarily in Polynesia, and from these certain factual information can be extracted, but only after critical evaluation. This body of material is diffuse and difficult to interpret, and still awaits a scientific processing which could make it more appropriate as a basis for studies of Polynesian and Micronesian prehistory. As most of the data on astronomy and navigation come from fairly recent Euro-American writings, one is justified in asking whether we are entitled to draw any conclusions from these concerning navigational methods within

Polynesia and Micronesia in pre-European times. This is a difficult question to answer, but it ought to be possible to make an appraisal of the matter against the following background.

The knowledge of nautical astronomy, and thus the navigational prowess, of a pre-literate people will be subject to a limit beyond which they can never reach. This limit is set by mathematical-physical laws and can only be surpassed through the use of technical aids, which we know the Polynesians and the Micronesians did not possess. For example, the determination of longitude, as well as navigation by a zenith star, requires access to an exact time-measurer, that is to say, a clock (chronometer), while a determination of the bearing to the sun during its diurnal path requires a comprehensive set of tables, etc.

If we are prepared to accept these facts, we can also conclude that on the whole the nautical-astronomical knowledge within Polynesia and Micronesia, as it presented itself in recent times, had developed as far as it could under the given conditions. Apart from a possible ability to determine latitude, and for this there is no evidence, the pre-European nautical astronomy did not surpass this stage.

One of the aims of this survey has been to render an account of the facts on which a reconstruction of the navigational methods can be based, taking into consideration that these facts probably reflect the situation in pre-European times. Naturally, there can be no absolute certainty that such a reconstruction is true, it can only have a certain degree of probability. In this connection it has also seemed important to point to the methods which have been attributed to the Polynesians even though no factual basis existed for these. In certain cases the methods ascribed are so advanced that they lay outside the limit of what the Polynesians were able to achieve. Unfortunately these fictitious methods are often referred to as if it were an established and universally accepted fact that they were used in Polynesian navigation. Consequently, many of the arguments presented in the debate on sea voyages in the Pacific Ocean are based on false premises.

Within Micronesia, where the basis for an interpretation of the navigational methods is more detailed than it is in Polynesia, it proved that it is not possible to group the methods of the different archipelagoes under one heading, Micronesian navigation. In view of this it may be wondered if there really exists anything that can be labelled Polynesian navigation. The Polynesian triangle encloses a vast area, in which the various island groups form relatively isolated, well-defined units. It seems that the geographical factors leading to the development of a purely regional astronomy and nautical astronomy are present here to the same extent as they are within Micronesia. Astronomy and the calendar have developed

in different directions within Polynesia, and the variations in, above all, the calendar are considerable. The basis of the nautical astronomy is meagre and does not permit any absolutely certain conclusions to be drawn. But from the little we do know, it appears as if, on the whole, there may have been a uniform nautical astronomy and method of navigation within Polynesia.

Nautical astronomy in Polynesia and Micronesia was based on the same principle, course setting by means of, primarily, the bearing of rising and setting heavenly bodies. Non-astronomical navigation in these two areas was also based on similar phenomena, the direction of the wind and the swell, making landfall with the aid of reflections, cloud formations, swell, etc. In trying to assess the possibilities afforded by these navigational methods, one should bear in mind that what is involved here is not just navigation either by stars or by the direction of the wind, and not just making a landfall by observing the swell and the natural aids to navigation, but a combination of all these methods, which a navigator with generations of experience behind him put into practice during his voyages. The whole is more than the sum of its parts.

When considering the accuracy of these methods and the results that could be achieved with them it is not possible to arrive at a satisfactory answer. Briefly the methods can be characterized as follows. Navigation towards a known destination was performed by dead reckoning. There was no possibility of determining the position accurately while the canoe was under way. The uncertainty of the canoe's position increased with the lapse of time owing to the effect of leeway, current and steering error. In principle the navigation became uncertain as soon as the canoe was out of sight of land. A successful landfall depended partly on the time taken by the voyage and partly on the characteristics of the "landfall zone" offered by the destination. The term "landfall zone" refers to the margin of error in navigation that could be tolerated and yet leave the seafarer with a fair chance of making a successful landfall. The size of this zone depended partly on the topography of the destination, its lateral extent and elevation, and partly on the special conditions characteristic of the intended destination, such as reflection, swell pattern, etc. The factors mentioned vary in respect of different destinations and do not remain constant for each of them.

Polynesians and Micronesians have reached and settled the great majority of the thousands of atolls and islands in the island world, even the most remote ones. How many of them set out on long ocean voyages, and how many of them survived to settle a newly discovered land? Under the given conditions, what were their chances of reaching a destination? Obviously these questions can never be answered. Speculations of this

kind would seem to belong more to the realm of probability theory than to that of navigation. From what we know of the navigational methods, however, it might seem justifiable to conclude that they were altogether too unreliable to permit regular contacts over distances, which required a long time at sea out of sight of land. At the moment it seems that this conclusion is confirmed by the archaeological investigations in the Pacific as yet in their early stages.

Polynesians and Micronesians were fully aware of the element of danger involved in sea voyages, whether long or short. Yet they set out. Their motives must have been very strong, especially in the case of ocean voyages which were in the nature of expeditions of discovery. But short voyages which took them to known areas could also seem hazardous. Gladwin has turned to psychology as a way of explaining this, and he has advanced his views in a study of canoe voyages in the Truk area:

"When asked they will admit that the dangers exist, but when pressed to explain their willingness to face them, they shrug the question off almost as if it were irrelevant. Instead of saying, as we might, that the goals were sufficiently important to justify the risk, they appear, like American automobile drivers, to disregard the possibility that it might be they who would die . . . This same lack of clearly formulated concern over the self or the future undoubtedly also helps them withstand the despair of being lost. In effect, they do not perceive that they have as much to lose as would we in such circumstances. Also, as we might expect, they are not as frightened over the possibility of death . . .

" . . . the contrast with our own society does make it appear that psychological variables cannot be ignored when considering why some people do and others do not travel in this fashion". (1958, pp. 897—898.)

Polynesians and Micronesians accomplished their voyages, not thanks to, but in spite of their navigational methods. We must admire them for their daring, their enterprise and their first-rate seamanship.

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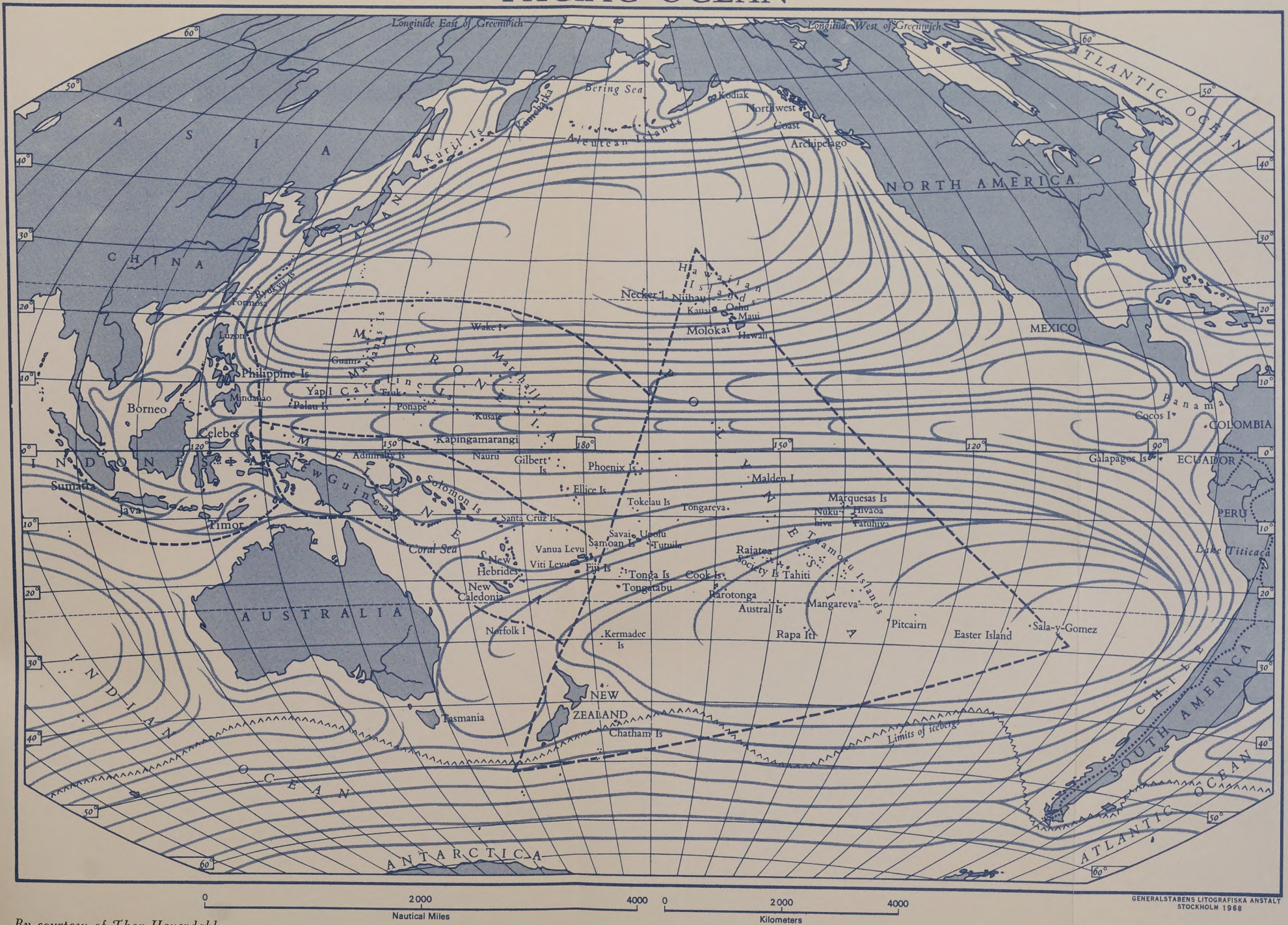
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